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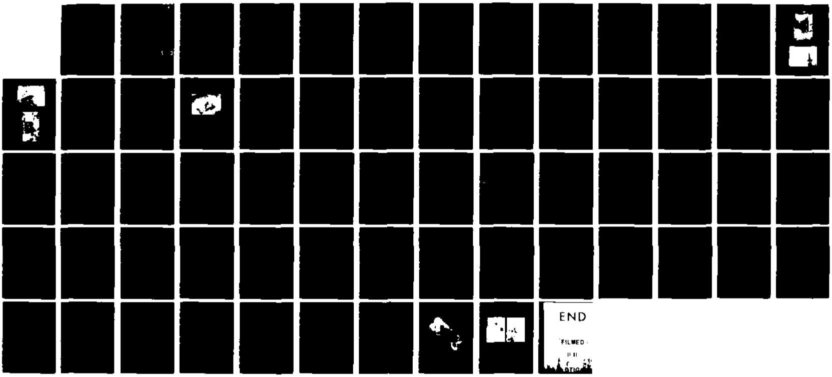

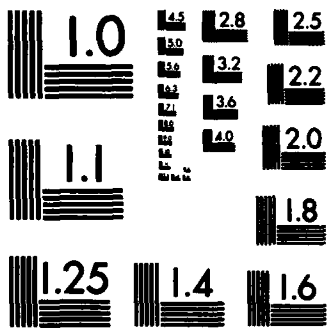
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Report No. 8308-X4400-201

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FINAL REPORT
F49620-82-C-0017
MAGNETIC FIELD COUPLED VELOCIMETERS

Submitted to

Air Force Office of Scientific Research
Bolling AFB

By

AMAF Industries, Inc.
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FLOW DIAGNOSTIC

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The velocimeter R&D program entered a "bench-top" scale experimental demonstration phase with the construction of a first prototype velocimeter drive-pickup coil array, a propane combustor test stand, and Z-80 based data acquisition/processing system. A computer code was written and successfully tested which modeled the response of the velocimeter array to flow field structures that could be realized on the test stand. Conventional

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cont diagnostics have been used to characterize the flow environment produced on the test stand. Preliminary testing of the velocimeter was begun at the end of the program year. Problems with signal detection and analysis were tentatively identified and possible solutions were under design.

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TABLE OF CONTENTS

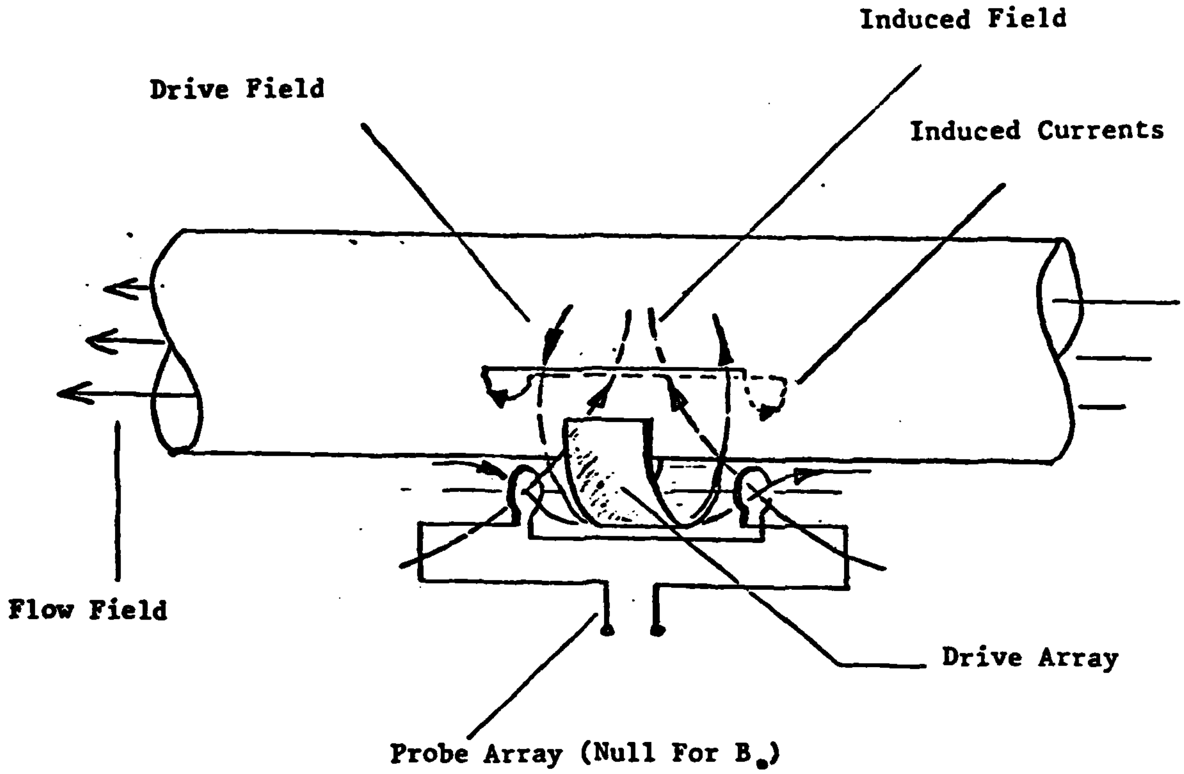
	Page
INTRODUCTION	1
STATEMENT OF WORK	3
STATUS OF RESEARCH	5
PROJECTIONS FOR THE NEXT PHASE	15
LIST OF JOURNAL PUBLICATIONS	15
PROFESSIONAL PERSONNEL (YEAR TWO)	16
INTERACTIONS AND PRESENTATIONS	16
PATENTS	17
APPENDICES:	
A. Contract Statement of Work (F49620-82-0017)	19
B. Abstract and Copies of Transparencies for Technical Presentation for AFOSR Meeting, Year Two	21
C. Outputs of Magnetic Field Line Following Computer Codes Applied to Velocimeter Coil Arrays	39
D. Source Code (FORTRAN) for Computer Model of Velocimeter Response to Flow Systems	45
E. Output of Computer Model for Velocimeter and Flow System	55
F. Abstract for AFOSR/AFRPL Chemical Rocket	59

INTRODUCTION

This report summarizes the results of the second year of a projected three year research program to demonstrate the viability of a totally nonintrusive, magnetically coupled velocimeter for high temperature, chemically reacting flows typical of rocket propulsion systems. The research involves theoretical analysis, numerical simulation, and experimental verification. Success in this effort would provide a much needed alternative diagnostic to existing mechanical, optical and electromagnetic flowmeter approaches.

In our approach (See Figure 1), a drive dipole magnetic field array produces a harmonically varying, spatially localized and controlled field which penetrates the flow-field to produce eddy and Lorentz-field currents. These currents are determined in part by flow boundary conditions. The fields produced by the currents (with distinguishable geometric structure) are picked up by a probe array designed (by lead-field theoretic techniques) to differentiate eddy currents from motional currents. The probe array is constructed to give null signals when coupling directly to the drive array. The spatial structure in the drive field and the probe field sensitivity provides the basis for determining the velocity structure of the flow-field. Since the coupling to the flow is purely inductive the diagnostic approach being developed here is uniquely non-intrusive.

Fig. 1



SCIENTIFIC APPROACH

- CHEMICALLY REACTING (CONDUCTING) FLOW-FIELD IS EXPOSED TO AC MAGNETIC FIELD.
- STRUCTURE OF INDUCED CURRENTS MEASURED BY A PROBE ARRAY ARE INVERTED BY LEAD-FIELD TECHNIQUES TO YIELD VELOCITY STRUCTURE.

ISSUES BEING ADDRESSED

- NO DIRECT CONTACT WITH FLOW (NON-INTRUSIVE).
- MEASUREMENT OF MEAN VECTOR FLOW VELOCITY FIELD, $\langle \underline{v}(\underline{r}) \rangle$ AND TURBULENT VECTOR FLOW-FIELD, $\Delta\underline{v}(\underline{r})$ (WITH DESIGN ASSUMPTION OF $|\Delta v/v| < 1$).

STATEMENT OF WORK

The research objectives for the second year were defined by the following tasks (see Appendix A for the Statement of Work as it appeared in the contract document):

a. Design and construct a data acquisition/data processing (DA/DP) interface based on a microprocessor for the velocimeter.

b. Design and construct a "bench top" scale seeded propane combustor test stand and calibrate the flowfield it produces using conventional diagnostic techniques.

c. Design and construct the first operating (prototype) configuration of the velocimeter array and develop a computer code for its specific parameters which predicts its responses to the test stand flowfields.

d. Test the velocimeter - DA/DP system on the combustor test stand and determine required configuration/system architecture changes.

STATUS OF THE RESEARCH

1. The DA/DP Interface:

The operating principle of the velocimeter requires the acquisition of signals from a spatially distributed set of pick-up coils (lead-field probes), conversion of the amplitude levels to digital equivalents, processing of the digitized signal data based on programmed algorithms and outputting of a velocity distribution uniquely determined by the data. Multiple samples of the data for varying drive coil weightings are taken under processor control. The DA/DP system design is shown in Figure 2 as being based on the following subsystems and components:

- Z-80 CPU
- AIM-12 (Dual) A/D Convertor Board
- AOM-12 (Dual) D/A Convertor Board
- V10-X1 Video Board
- Disk Controller Board (2422)
- Disk Drive - 5 1/4" (SA-400)
- RAM Board

On the A/D convertor board, 16 channels can be acquired by multiplex differentially or 32 channels single-ended with resistor programmed gain. Separate sample and hold (S/H) parallel channels for amplifying, sampling and holding the low level signals from the pick-up coils have been designed, constructed and tested. The parts for the entire DA/DP system parts have been acquired and incorporated into a system but the system itself has not

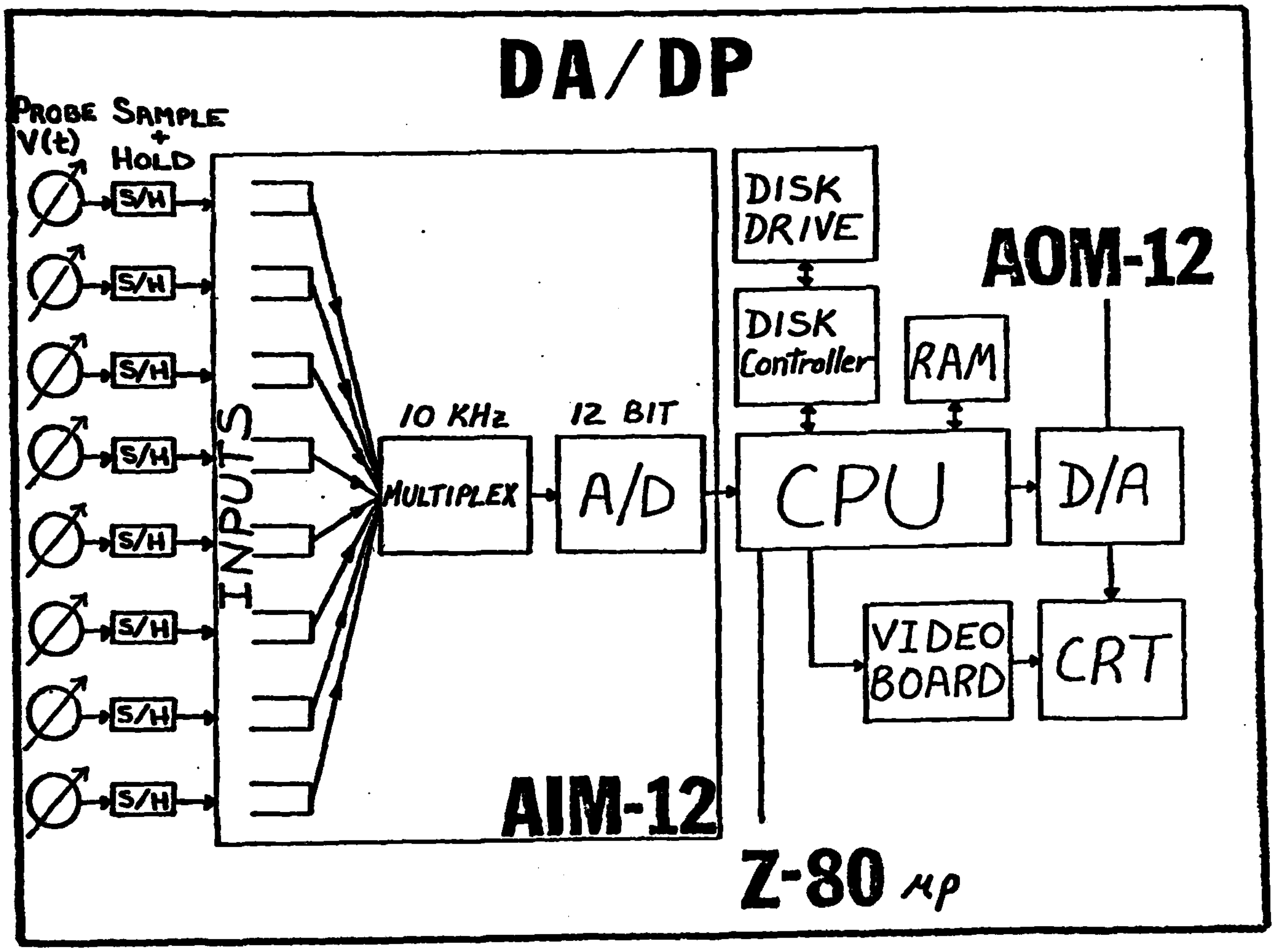

DA/DP
PROBE V(t)
SAMPLE + HOLD
S/H
INPUTS
10 KHz
MULTIPLEX
12 BIT
A/D
AIM-12
DISK DRIVE
DISK Controller
RAM
AOM-12
CPU
D/A
VIDEO BOARD
CRT
Z-80 μp

FIGURE 2.

yet been fully exercised. The design of the system placed highest priority on use flexibility (programmability). Little difficulty is expected verifying its applicability to this application.

2. THE COMBUSTOR TEST STAND:

The test stand (see Figure 3) consists of a steel mounting stand, an exhaust hood, a propane bottled gas supply, and combustor head. The combustor head is constructed from three (commercially) standard 1/2" O.D. propane torch heads strapped tightly together to form a triangular burner cross-section. The flow rate of propane to each head can be controlled separately so as to allow for a controllable, continuously variable transition from a single burner circular cross-section flame to a full triangularly symmetric cross-section. Figure 4 shows the flame structure formed by a single burner. The flames are sodium ion seeded by passing the flames over a salt (NaCl) coated steel wire mounted at the center of the burner array. The wire tip is visible at the flame base in Figure 4. The flame temperature is estimated (for in-air combustion of propane) at approximately 2000°F. The flow velocity was measured by time-of-flight techniques using 1 cm. spaced biased gaps (800 VDC). The flame flow transported spark channel registered by the gaps was produced by a 20kV, 1 joule discharge pulse from a pulse generator. Flow velocities of 20 m/sec could be reliably produced and measured on the test stand. Figures 5 and 6 shows the time-of-flight gaps positioned in front of the velocimeter array.

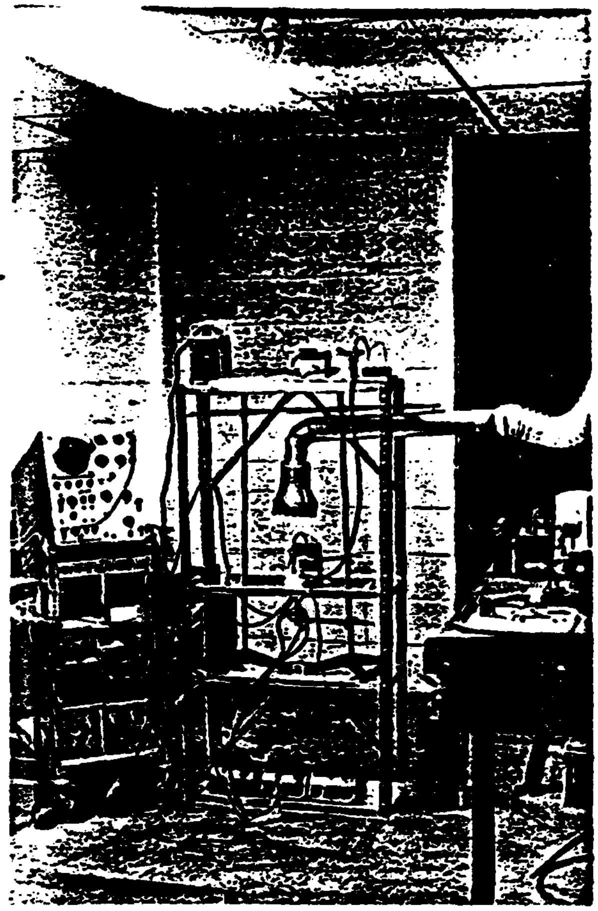


FIGURE 3.

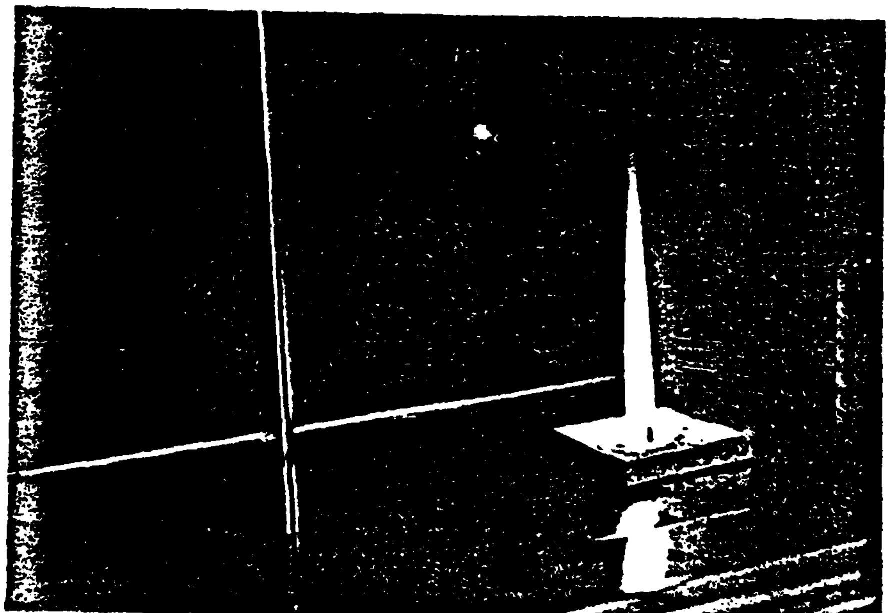


FIGURE 4.

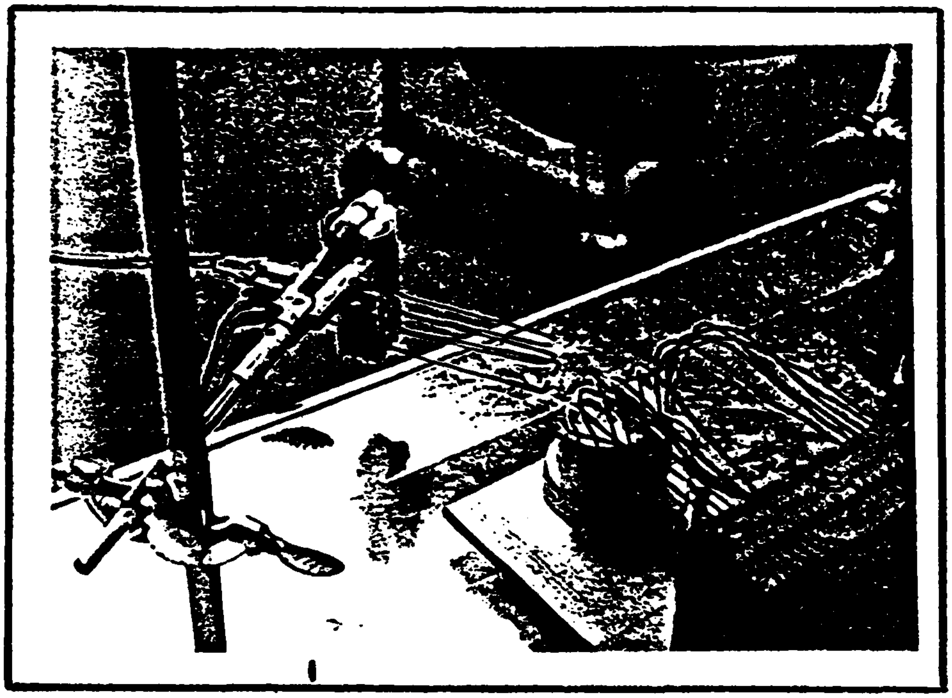


FIGURE 5.

FIGURE 6.

3. THE VELOCIMETER ARRAY:

The prototype velocimeter consists of two array systems - the drive array coils and the pick-up array coils (see Figure 7). The drive coils (6) are 1 centimeter in diameter, contain 40 turns each, and form a semi-circle 20 centimeters in diameter. They are typically driven by a signal generator at frequencies of 100 kH_z to 1 MH_z. They are shown with dipole moments all aiding (all + 1 weights) but through a set of sliding (or solid-state) switches they can be quickly reconnected to yield any chosen combination of ± 1 dipole weights. Each array weight choice yields a corresponding drive magnetic field and vector magnetic potential. The pick-up array consists in the prototype of two coils 1 centimeter in diameter, containing 10 turns each, positioned symmetrically above and below the drive array. They are shown connected in such a way as to cancel any eddy-effect or direct transformer coupling signals and so as to be sensitive only to flow velocity produced signals. These arrays systems are held rigidly in place by plaster molding and are accessed by wire assemblies and coaxial cable. A rear view of the array and feeds is shown in Figure 8.

The fields created by the drive array has been modelled by computer and the structure completely mapped by field line following codes (see Appendix C). A large computer code has been written and tested for internal consistencies which models the complete interaction between the drive array the flame flow field and the pick-up array. The drive array coil weights, the pick-up coil configuration and the velocity structure are input parameter and the voltage out of the pick-up array is the output. The source code is shown in Appendix D and typical outputs are shown in Appendix E. Table 1 presents representative results of taking as a velocity structure (in cylindrical coordinates):

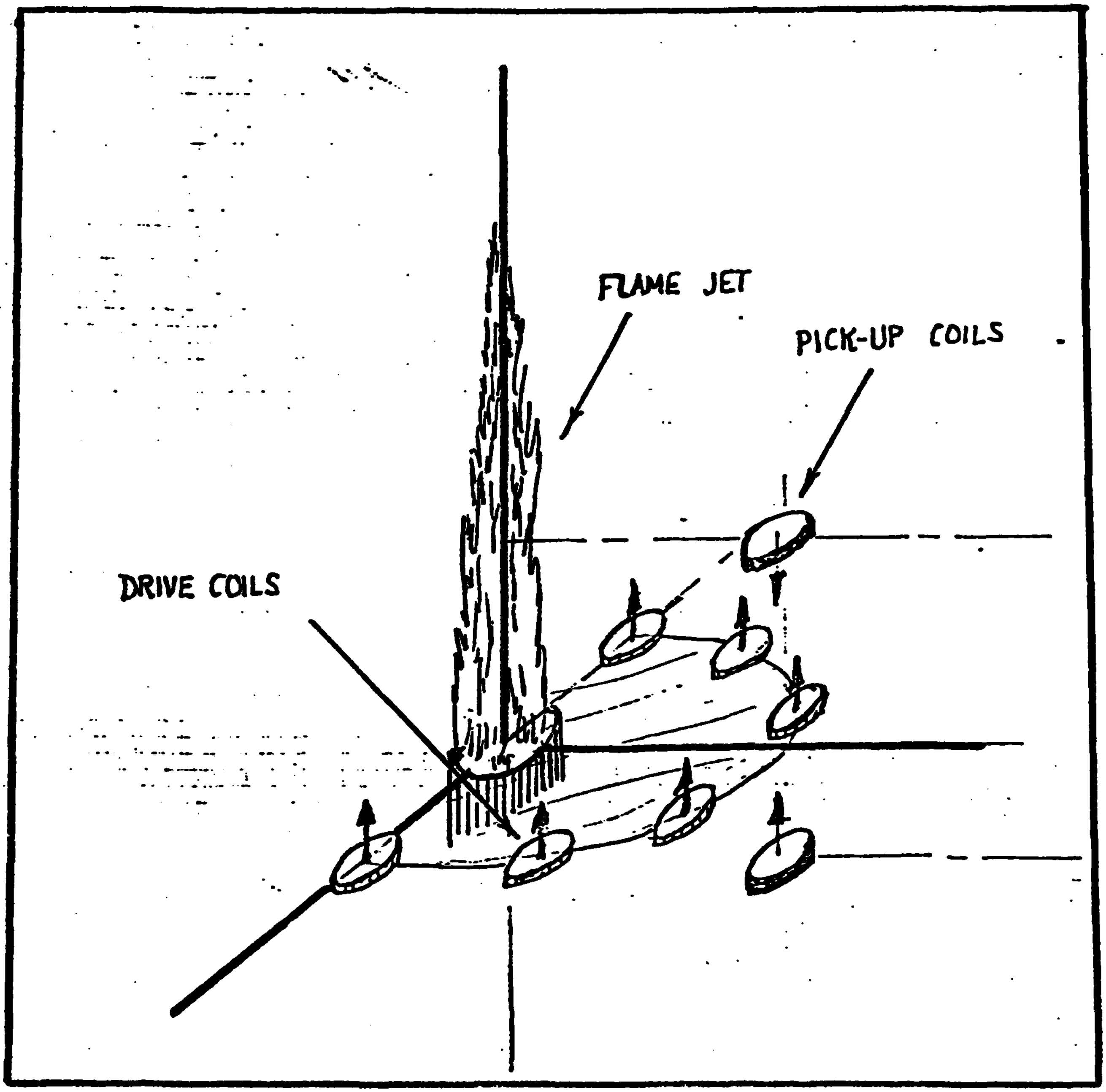


FIGURE 7.

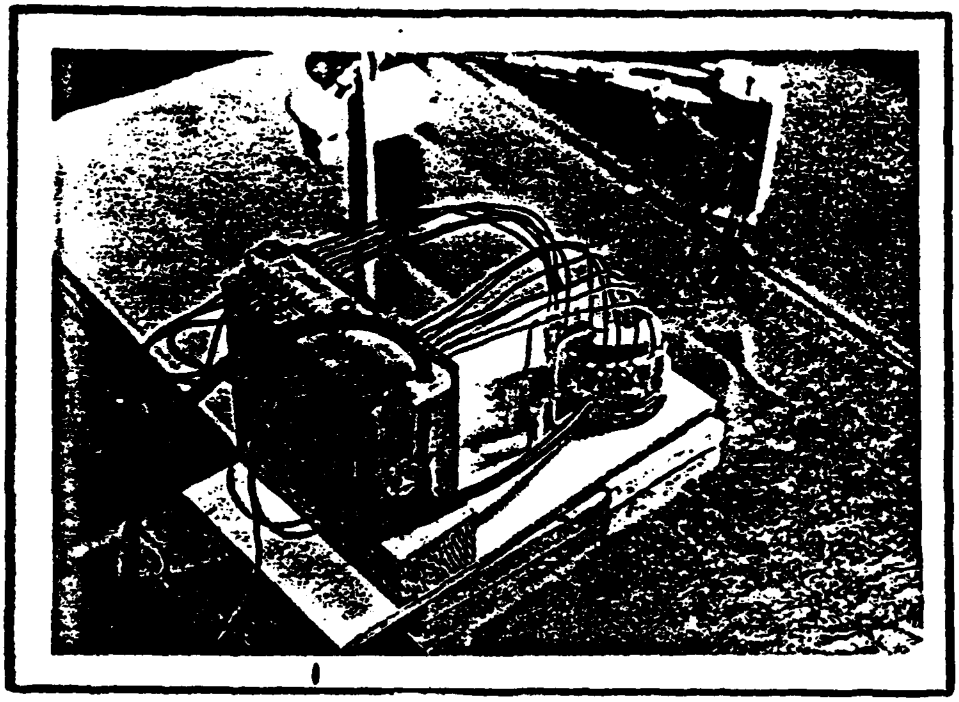


FIGURE 8.

TABLE 1.

ARRAY WEIGHTS

Velocity Profiles $v(r,\phi)$	1	2	3	4	5
	+1+1+1+1+1+1	+1-1+1+1-1+1	+1+1-1-1+1+1	+1-1+1-1-1-1	+1-1+1-1+1-1
$J_0(r)$	0.25E 0	0.84E-1	-0.14E 0	-0.84E-1	0.27E-8
$J_0(r)+0.67J_3(r)\cos 3\phi$	0.25E 0	0.84E-1	-0.14E 0	-0.87E-1	-0.74E-2
$J_0(r)-0.67J_3(r)\cos 3\phi$	0.25E 0	0.84E-1	+0.14E 0	0.80E-1	0.74E-2
$J_0(r)+0.67J_3(r)\sin 3\phi$	0.24E 0	0.67E-1	-0.13E 0	-0.84E-1	0.59E-9
$J_0(r)-0.67J_3(r)\sin 3\phi$	0.27E 0	0.10E 0	-0.15E 0	-0.83E-1	-0.59E-9

VELOCIMETER OUTPUTS

$$\bar{V} = V(r,\phi)\,\hat{e}_z \quad \text{where}$$

$$V(r,\phi) = J_o(r) \pm 0.67\, J_3(r) \cos 3\phi, \pm 0.67\, J_3(r) \sin 3\phi$$

Those velocity structures all have the same total mass flow rates but have different flow spatial structures (including triangular symmetries). The computer results predict, as expected, that the spatial structure of the flow can be distinguished through a sampling process based on selectable drive-coil weights.

4. TEST OF THE VELOCIMETER - DA/DP SYSTEM ON THE TEST STAND:

At the end of Year Two, the actual on-stand testing of the system was just underway. Preliminary data shows that there will be difficulty in suppressing eddy and transformer signals while maintaining sensitivity to flow velocity effects (some levels being separated by three orders of magnitude or more scale). Approaches to solving these and other associated experimental difficulties in proving the velocimeter will be proposed for Year Three activity.

PROJECTIONS FOR THE NEXT PHASE

A proposal for a third year of effort is in preparation. That year would bring to experimental closure the foundations laid in the first two years. It would include the following activities:

a. Programming of the Z-80 for the particular requirements of acquisition and processing of the velocimeter prototype.

b. Conversion of the propane-air combustor head to use propane-oxygen. This is expected to raise the flame temperature significantly and the flame conductivity by nearly an order of magnitude (thus easing some of the induced signal detection problems).

c. Improving the drive array power supply to higher power and improving the design of both the drive and pick-up arrays towards greater signal sensitivity.

d. Thorough testing of the system to establish <u>intrinsic</u> limitations of the approach.

LIST OF JOURNAL PUBLICATIONS

There have been no journal publications resulting from the research as yet. It is anticipated that results of publishable interest and substance will be available at the completion of the phase of experimental testing of the diagnostic on a "bench-top" combustor which is now well underway.

PROFESSIONAL PERSONNEL (YEAR TWO)

Principal Investigator - Dr. Carl Spight

Responsible for overall research direction, technical validity, and project management.

Members of Technical Staff - Dr. Ronald Graves, Dr. Carlos Handy

Responsible for mathematical analysis and computer modelling effort.

Member of Technical Staff - Mr. Robert Miller

Responsible for execution of experimental program.

INTERACTIONS AND PRESENTATIONS

A status report on the research effort early in Year Two was presented at the AFOSR Meeting on Diagnostics of Reacting Flows on February 26, 1982 in Stanford, California (Stanford University). The abstract and copies of transparencies presented are provided as Appendix B.

In addition, on April 9, 1982, a trip was made to Princeton, New Jersey to discuss the applicability of our diagnostic approach to measurement requirements in the research of Dr. Moshe BenReuven at the Princeton Combustion Research Laboratories. The detailed discussions focused on the possibility of the non-intrusive measurement of velocity flow structures in wall-layers in combusting flow chambers. No firm conclusions were drawn although it was agreed that an appropriate next step would

be to determine the possibility of funding for such investigations in carefully controlled, highly simplified flow-field systems.

PATENTS

No patents have been derived or applied for from this work to date.

APPENDIX A

Contract Statement of Work (F49620-82-C-0017)

SECTION B - SUPPLIES/SERVICES AND PRICES

0001 RESEARCH

The contractor shall furnish the level of effort specified in Section F, together with all related services, facilities, supplies and materials needed to conduct the research described below. The research shall be conducted during the period specified in Section F.

0001AA

a. Design a data acquisition/data processing (DA/DP) interface based on a microprocessor for the velocimeter coil system that will be capable of yielding velocity profile outputs on a CRT or as hard copy on a plotter.

b. Construct the DA/DP interface as a rack mounted system and test it to the design specifications.

c. Test the velocimeter with the DA/DP interface using the electrolytic flow chamber to verify overall system design.

d. Construct a "bench-top" scale seeded propane combustor facility, calibrate the flow field using conventional techniques and construct a support frame for attaching the velocimeter coil array.

e. Test the velocimeter with DA/DP interface on the combustor facility and analyze results against known combustor flow parameters.

f. Redesign the velocimeter system based on the combustor test and modify the design to optimize its operation in measurement of mean flow parameters.

APPENDIX B

Abstract and Copies of Tranparencies for Technical Presentation, February 26, 1982 at AFOSR Meeting on Diagnostics of Reacting Flows

MAGNETIC FIELD COUPLED VELOCIMETERS

Dr. Carl Spight

AMAF Industries, Inc.
Columbia, Maryland

A program of theoretical analysis, computer simulation, and experimental verification is underway which will demonstrate the feasibility of a totally non-intrusive flow-field diagnostic for weakly turbulent, high temperature chemically reacting flows. The effort will result in viable designs for AC magnetic field-coupled velocimeters capable of accurately measuring the mean and the turbulent velocity structure of flow-fields typical of rocket combustion chambers and exhaust nozzles.

Approach (See Fig. 1)

A drive dipole magnetic field array produces a harmonically varying, spatially localized and controlled field which penetrates the flow-field to produce eddy and Lorentz-field currents. These currents are determined in part by flow boundary conditions. The fields produced by the currents (with distinguishable geometric structure) is picked up by a probe array designed (by lead-field theoretic techniques) to differentiate eddy currents from motional currents. The probe array is constructed to give null signals when coupling directly to the drive array. The spatial structure in the drive field and the probe field sensitivity provides the basis for determining the velocity structure of the flow-field. Since the coupling to the flow is purely inductively the diagnostic approach being developed here is uniquely non-intrusive.

Fig. 1

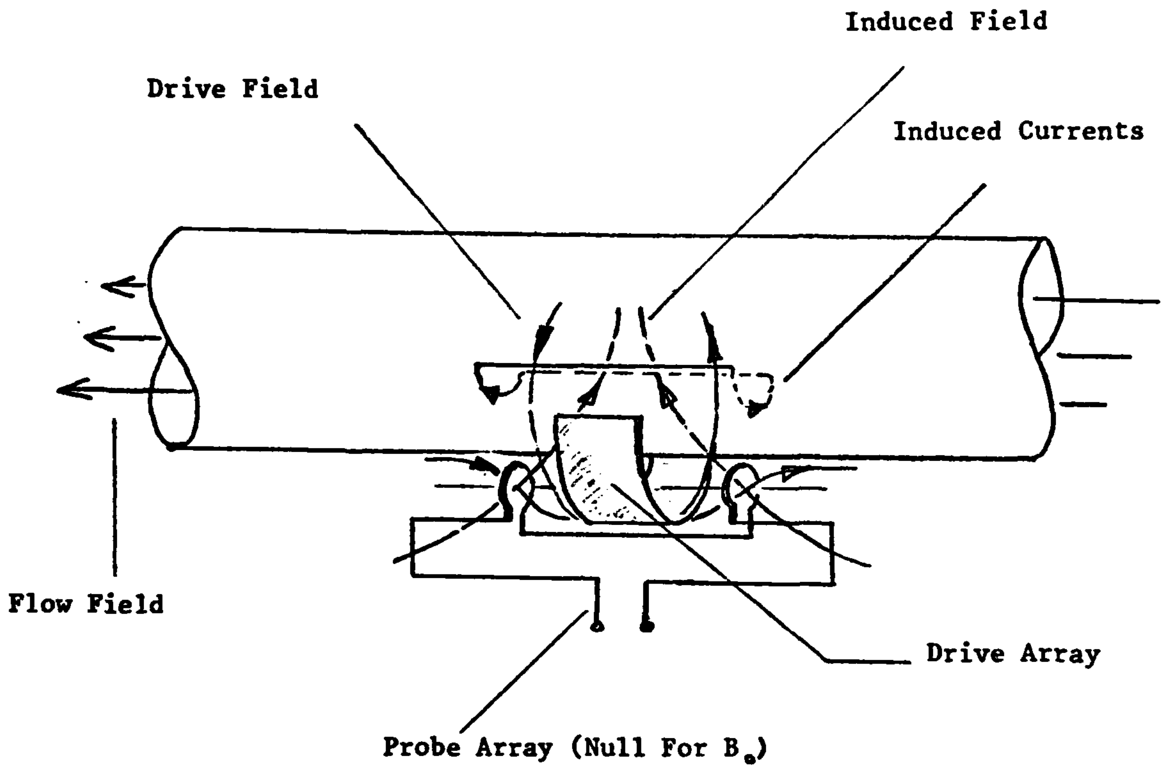


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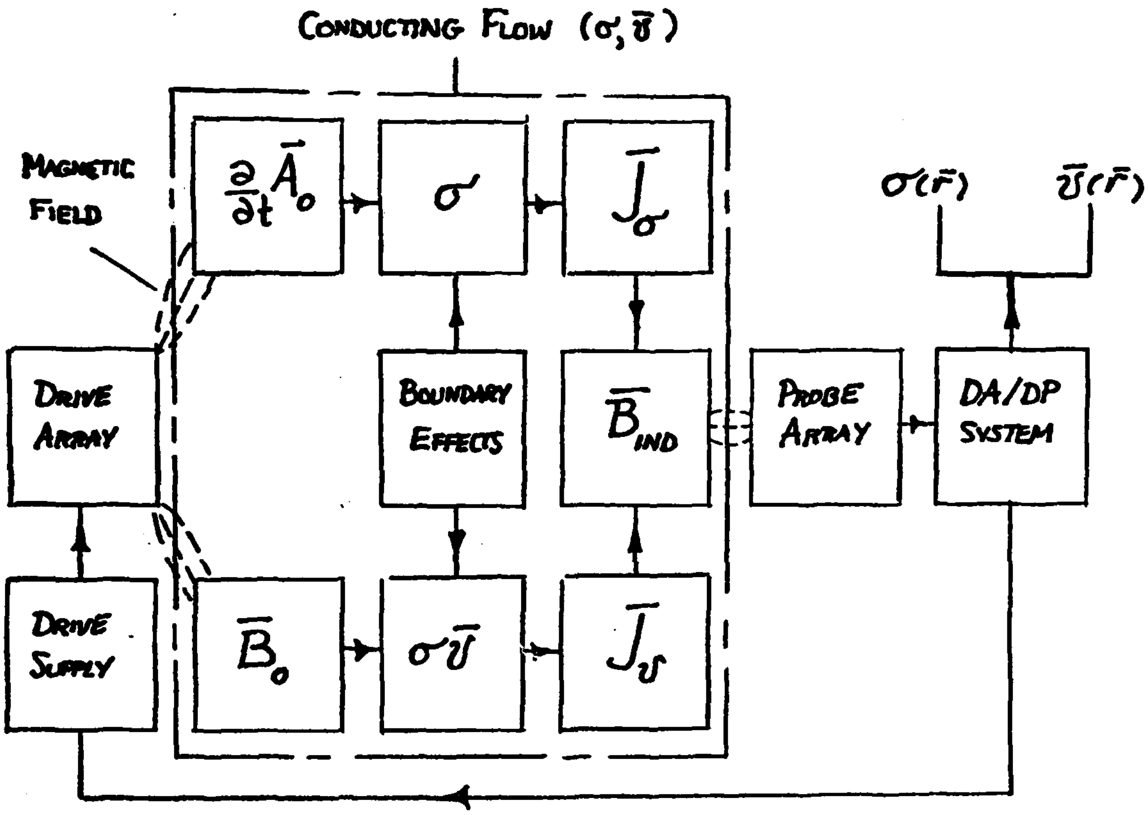
Fig. 2



BASIS: $$\nabla \times \bar{B}_{IN} = \mu_0 \sigma \left(-\frac{\partial}{\partial t}\bar{A}_0 + \bar{v} \times \bar{B}_0 - \nabla \psi_{BOUNDARY} \right)$$

Accomplishments.

- Theoretical analysis well elaborated with all important effects
- Computer code implementing theory developed for slab and cylindrical flow models
- Electrolytic chamber test of theory validated basic approach including treatment of boundary effects
- The data acquisition/data processor system (DA/DP) has been designed. Its construction is underway.

SCALES:

$$\frac{\varepsilon_0 \omega}{\sigma} \ll 1$$

$$L^2 \mu_0 \sigma \omega \ll 1$$

$$L \mu_0 \sigma v \ll 1$$

SYMBOLS:

$\bar{r}$	An (Arbitrary) Vector Position
$f(\bar{r})$	A Scalar Field
$\overline{f(\bar{r})}$	A Vector Field
$\bar{B}_o(\bar{r})$	Magnetic Field for Drive Array
$\bar{A}_o(\bar{r})$	Vector Magnetic Field for Drive Array
$\bar{J}_o(\bar{r})$	Current Density in Drive Array (Equivalent Distribution)
$\bar{U}(\bar{r})$	Velocity Field for Flow-Field
$\sigma(\bar{r})$	Scalar Conductivity Field for Flow-Field
$\psi(\bar{r})$	Electrostatic Potential Field Associated with Boundary Effects
$\hat{n}$	Surface Unit Normal
$\bar{J}_\sigma$	Eddy Current
$\bar{J}_U$	Motion Associated Current
ω	AC Frequency of Drive Array
$\bar{B}_{IND}$	Induced Magnetic Field
V_{PROBE}	Voltage Induced in Probe Array
$\bar{\mathcal{E}}_{LEAD}(\bar{r})$	Electromotive Force Per Unit Current (Lead Field) Produced by Probe if Reciprocally Driven by Current
$\bar{\mathcal{A}}_{LEAD}(\bar{r})$	Vector Magnetic Field Per Unit Current Produced by Probe if Reciprocally Driven Current
$G_N(\bar{r},\bar{r}')$	Neumann Green's Function for Boundary Surface for Conducting Fluid

MODELS EQUATIONS:

1. $$\bar{B}_o \equiv \nabla \times \bar{A}_o \quad , \quad \nabla \times \bar{B}_o = \mu_o \bar{J}_o$$

2. $$\nabla \times \bar{B}_{IND} = \mu_o \left\{ \bar{J}_\sigma + \bar{J}_v \right\}$$

3. $$\bar{J}_\sigma = \sigma (- i\omega \bar{A}_o - \nabla \psi_\sigma)$$

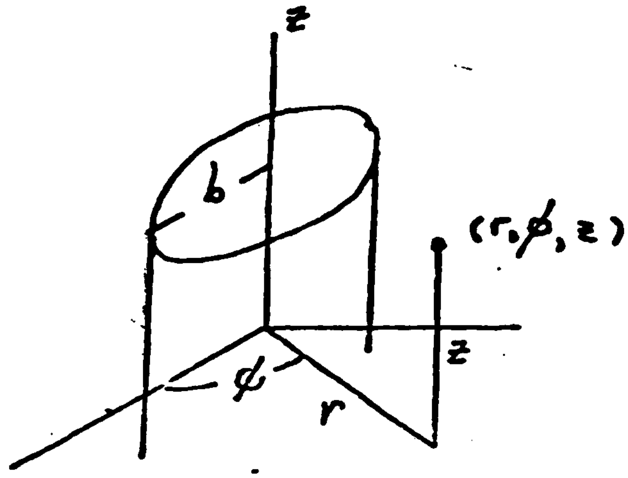
4. $$\bar{J}_v = \sigma (\bar{v} \times \bar{B} - \nabla \psi_v)$$

5. $$\nabla^2 \psi_\sigma = \nabla^2 \psi_v = 0$$

6. $$\psi_\sigma = - \frac{1}{4\pi} \int_{BOUNDARY} (i\omega \bar{A}_o) G_N(\bar{r}, \bar{r}') \, dS'$$

7. $$\psi = \frac{1}{4\pi} \int (\bar{v} \times \bar{B}_o) G_N(\bar{r}, \bar{r}') \, dS'$$

8. $$V_{PROBE} = \int \left\{ \bar{J}_o + \bar{J}_\sigma + \bar{J}_v \right\} \cdot \underbrace{- i\omega \bar{A}_{LEAD}}_{\bar{E}_{LEAD}} dV'$$



$$G_N(\bar{r},\bar{r}') = \frac{2}{\pi}\sum_{m=-\infty}^{\infty} e^{i(\phi-\phi')}\int_0^{\infty} dk \cos[k(z-z')]$$

$$\times \frac{I_m(kr_<)}{I_m'(kb)}\left[I_m'(kb)K_m(kr_>) - I_m(kr_>)K_m'(kb)\right]$$

On Surface $r_> \to b$:

$$G_N(\bar{r},\bar{r}') = -\frac{2}{\pi b}\sum_{m=-\infty}^{\infty} e^{im(\phi-\phi')}\int_0^{\infty}\frac{dk}{k}\cos[k(z-z')]\,\frac{I_m(kr)}{I_m'(kb)}$$

CYLINDRICAL GEOM:

TAKE $\bar{v}(\bar{r}) = v(r)\,\hat{e}_z$

$$\therefore\ \bar{v} \times \bar{B}_0 = \bar{v} \times (\nabla \times \bar{A}_0)$$

$$= v(B_r\,\hat{e}_\phi - B_\phi\,\hat{e}_r)$$

$$= v\left[\frac{1}{r}\frac{\partial}{\partial\phi}A_z - \frac{\partial}{\partial z}A_\phi\right]\hat{e}_\phi$$

$$-v\left[\frac{\partial}{\partial z}A_r - \frac{\partial}{\partial r}A_z\right]\hat{e}_r$$

NOW CAN REQUIRE (FOR EXAMPLE)

$A_z \equiv 0 \quad (\hat{M} \equiv \hat{e}_z)$

ALSO CAN FIND REGION WHERE $A_\phi \gg A_r$

$$\therefore\ \bar{v} \times \bar{B}_0 \rightarrow -v(r)\frac{\partial}{\partial z}A_\phi\,\hat{e}_\phi$$

TAKE $\bar{M}_0 = [\sin\alpha\, \hat{e}_r + \cos\alpha\, \hat{e}_z]\, m_0(\phi)\, \frac{\delta(r-R_0)}{2\pi r}\, \delta(z)$

WHERE $m_0(\phi) = m_0 \left[1 + \sum_{m=1}^{\infty} (A_m \cos m\phi + B_m \sin m\phi)\right]$

$$\therefore \begin{bmatrix} A_r \\ A_\phi \\ A_z \end{bmatrix}_0 = \frac{\mu_0 m_0}{4\pi} \nabla \times \left[\begin{matrix} \sin\alpha\, \varphi_{11} \\ 0 \\ \cos\alpha\, \varphi_{00} \end{matrix} \right.$$

$$+ \frac{1}{2} \sum_{m=1}^{\infty} A_m \begin{Bmatrix} \sin\alpha \cos m\phi\, (\varphi_{m+1\, m+1} + \varphi_{m-1\, m-1}) \\ \sin\alpha \sin m\phi\, (\varphi_{m+1\, m+1} - \varphi_{m-1\, m-1}) \\ 2\cos\alpha \cos m\phi\, \varphi_{mm} \end{Bmatrix}$$

$$\left. + \frac{1}{2} \sum_{m=1}^{\infty} B_m \begin{Bmatrix} \sin\alpha \sin m\phi\, (\varphi_{m+1\, m+1} + \varphi_{m-1\, m-1}) \\ -\sin\alpha \cos m\phi\, (\varphi_{m+1\, m+1} - \varphi_{m-1\, m-1}) \\ 2\cos\alpha \sin m\phi\, \varphi_{mm} \end{Bmatrix} \right]$$

AND $\varphi_{ij} \equiv \int_0^\infty dk\, \epsilon^{-kz} J_i(kr) J_j(kR_0)$

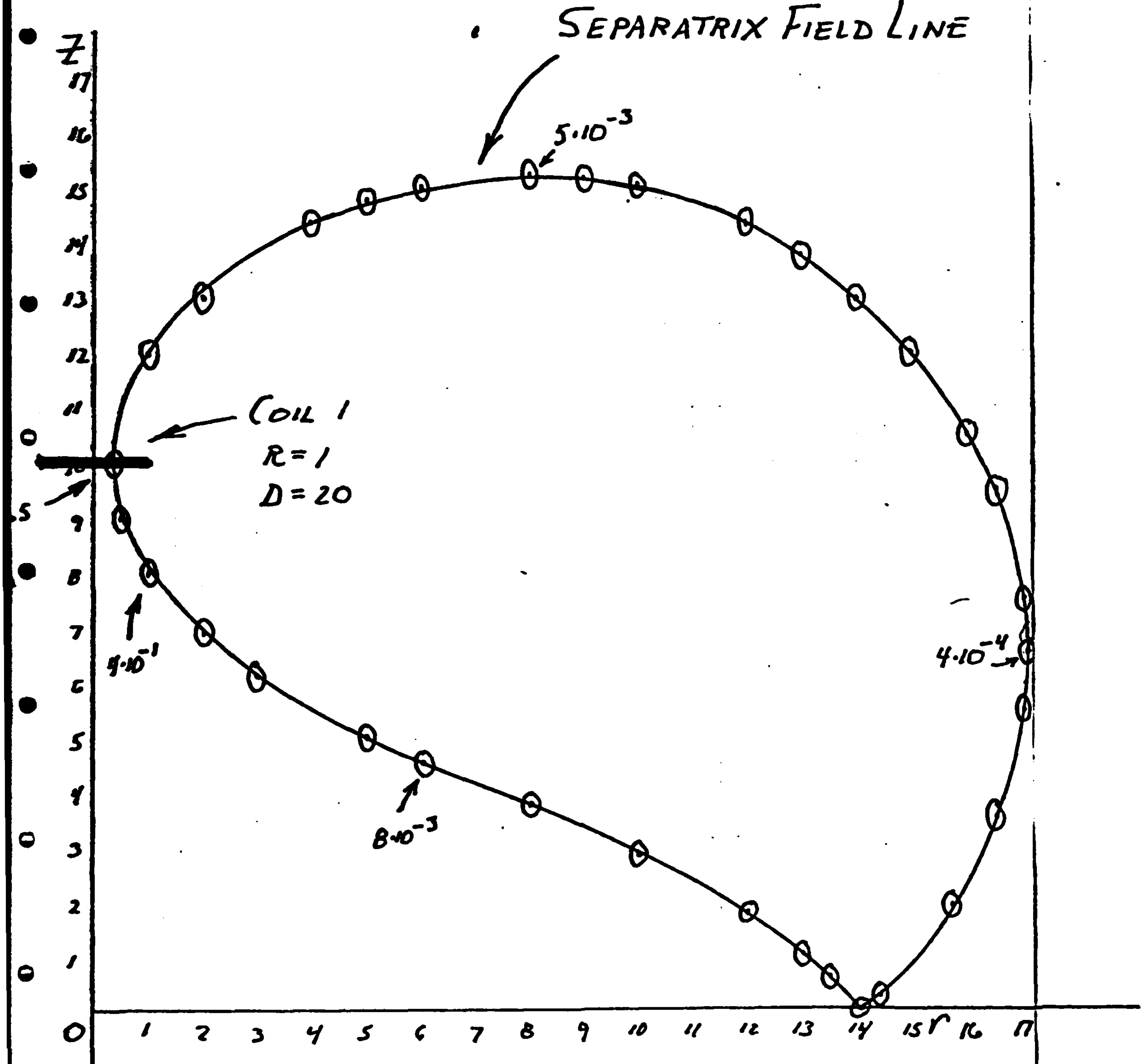
$$\therefore V_{OUT} = \int \sigma\, i\omega\, v(r) \frac{\partial}{\partial z} A_\phi\, A_{LEAD_\phi}\, dV'$$

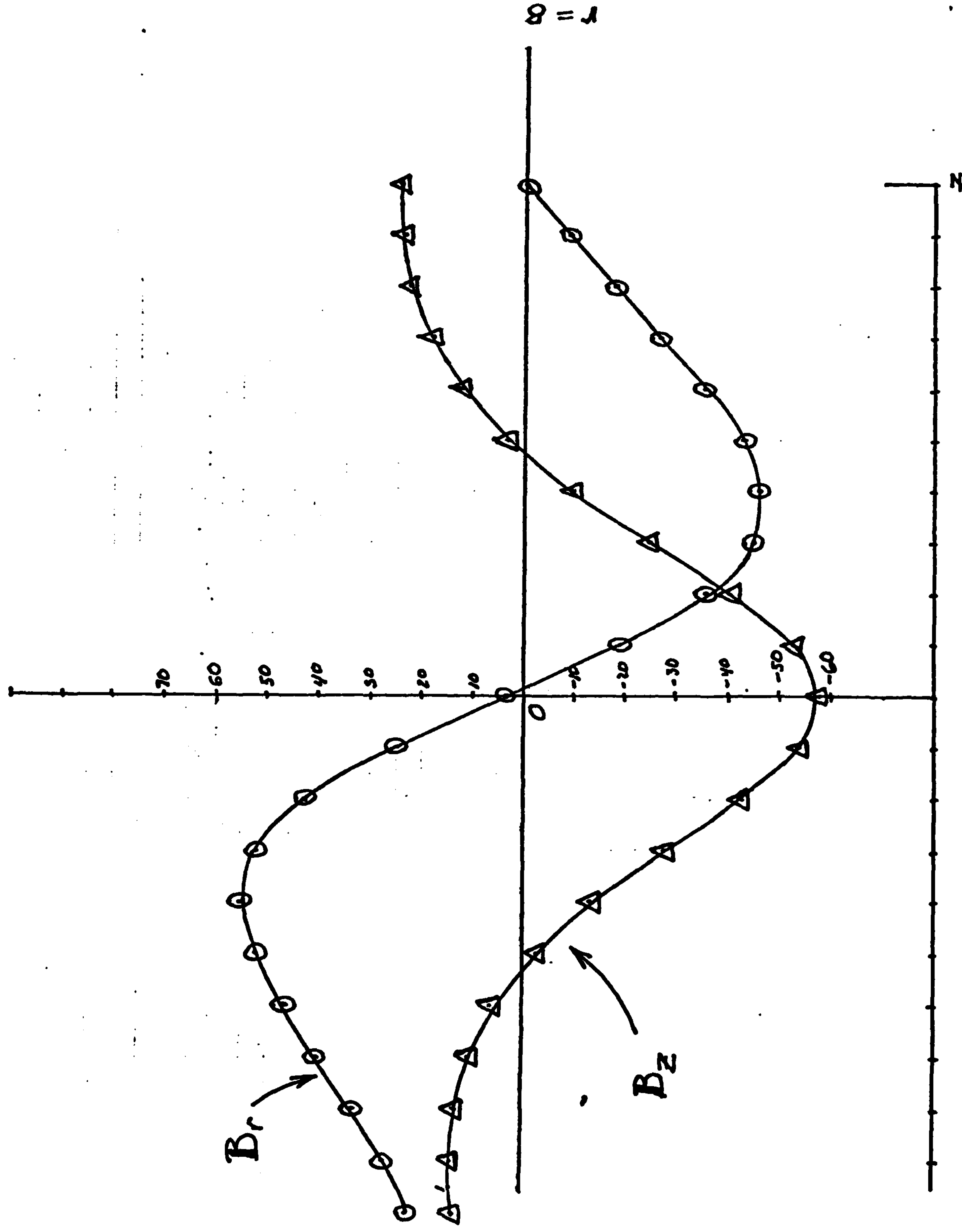
$$= i\omega\sigma \int_0^b dr\, v(r) \int d\phi \int dz\, \frac{\partial}{\partial z} A_\phi\, A_{LEAD_\phi}$$

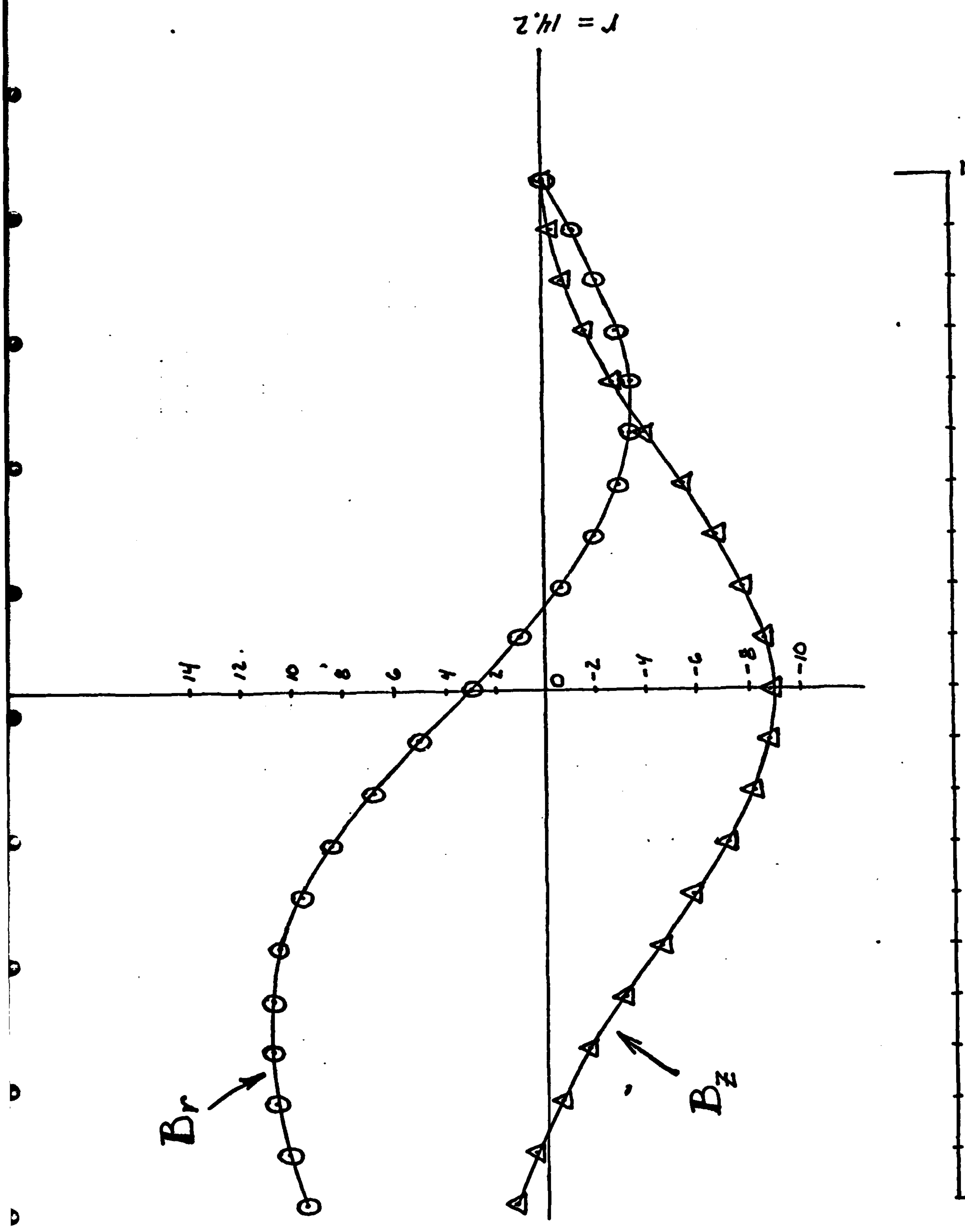
$$= \int_0^b dr\, v(r)\, \tilde{\mathcal{J}}(r)\, \sigma$$

WHERE $\tilde{\mathcal{J}}(r) \equiv i\omega \int d\phi \int dz\, \frac{\partial}{\partial z} A_\phi\, A_{LEAD_\phi}$

$$= \tilde{\mathcal{J}}\left(J_m(\zeta r) \right)$$


SEPARATRIX FIELD LINE
$5\cdot10^{-3}$
COIL 1
R = 1
D = 20
.5
$4\cdot10^{-1}$
$4\cdot10^{-4}$
$8\cdot10^{-3}$
Z
r
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17


r = 8
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
z
B_r
B_z

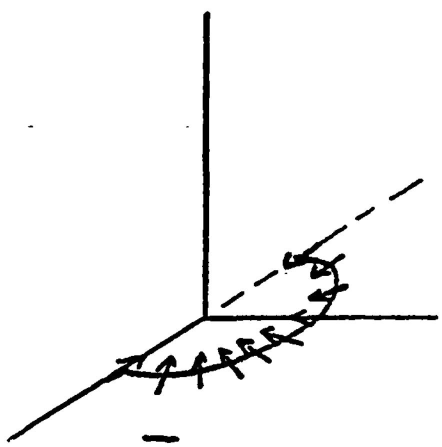


r = 14.2
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
Br
Bz
Z

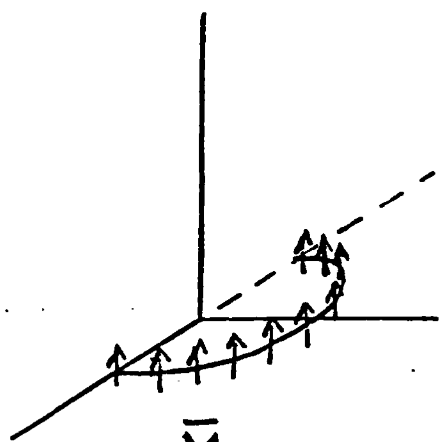
$$\bar{r} \equiv (r, \phi, z)$$

$$\bar{M}_{\rightarrow}(\bar{r}) = -m_0 \, \delta(z) \, \frac{\delta(r-R_0)}{2\pi r} \, \hat{e}_r \left[1 - u(\phi - \pi)\right]$$

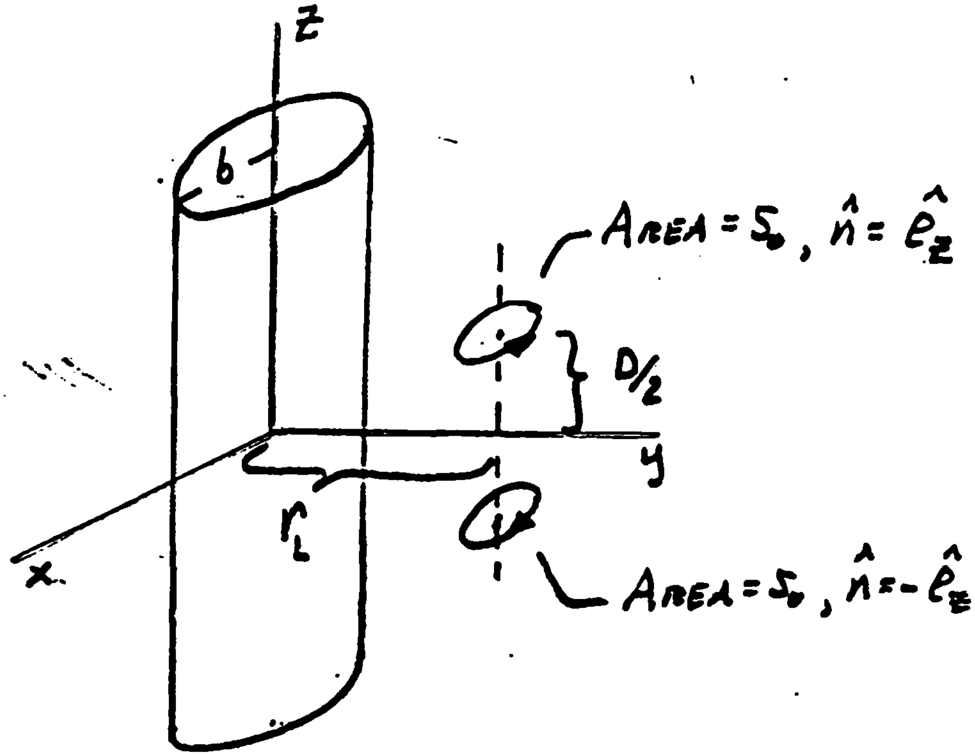
$$\bar{M}_{\uparrow}(\bar{r}) = m_0 \, \delta(z) \, \frac{\delta(r-R_0)}{2\pi r} \, \hat{e}_z \left[1 - u(\phi - \pi)\right]$$



$\bar{M}_{\rightarrow}$



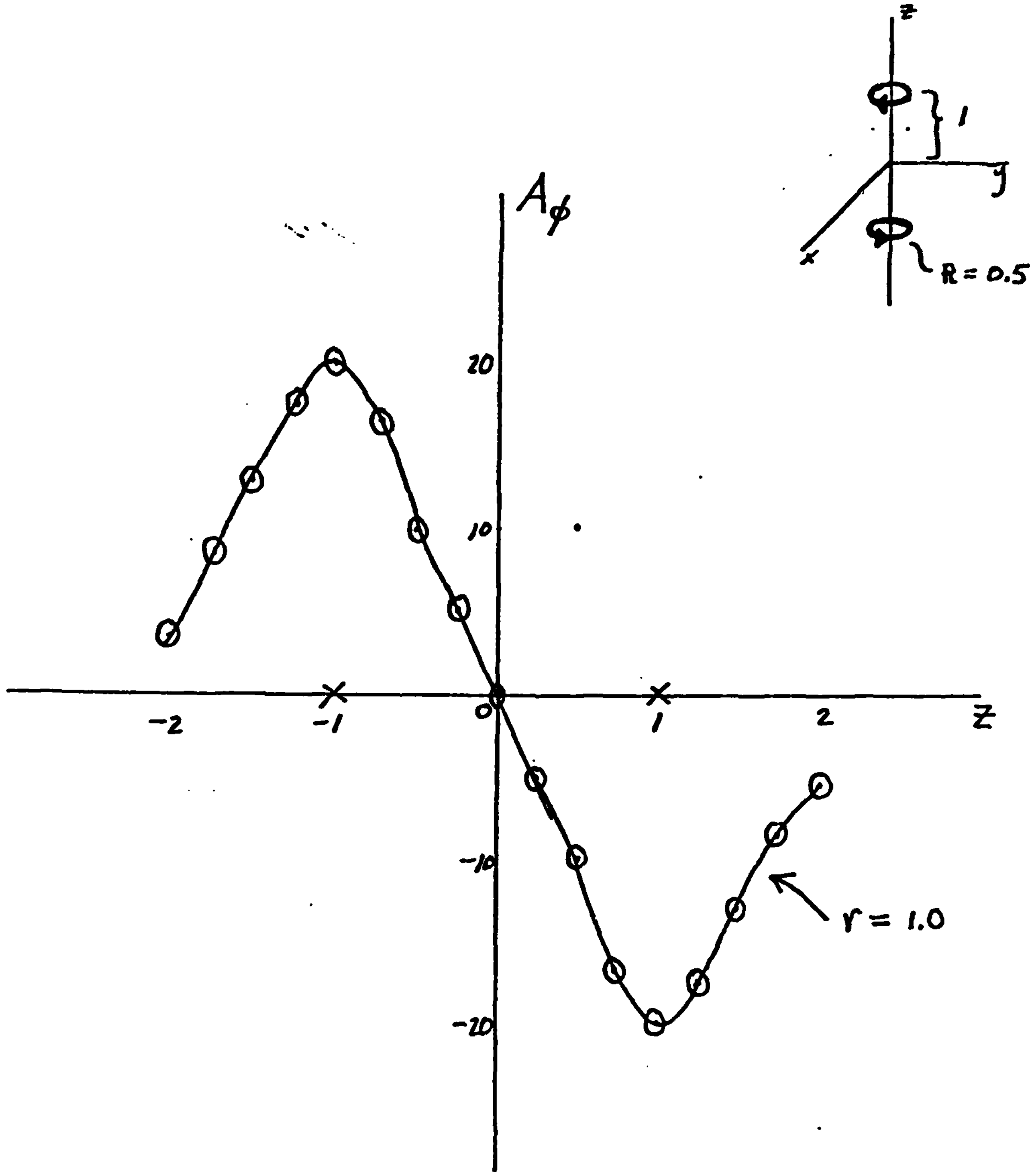
$\bar{M}_{\uparrow}$



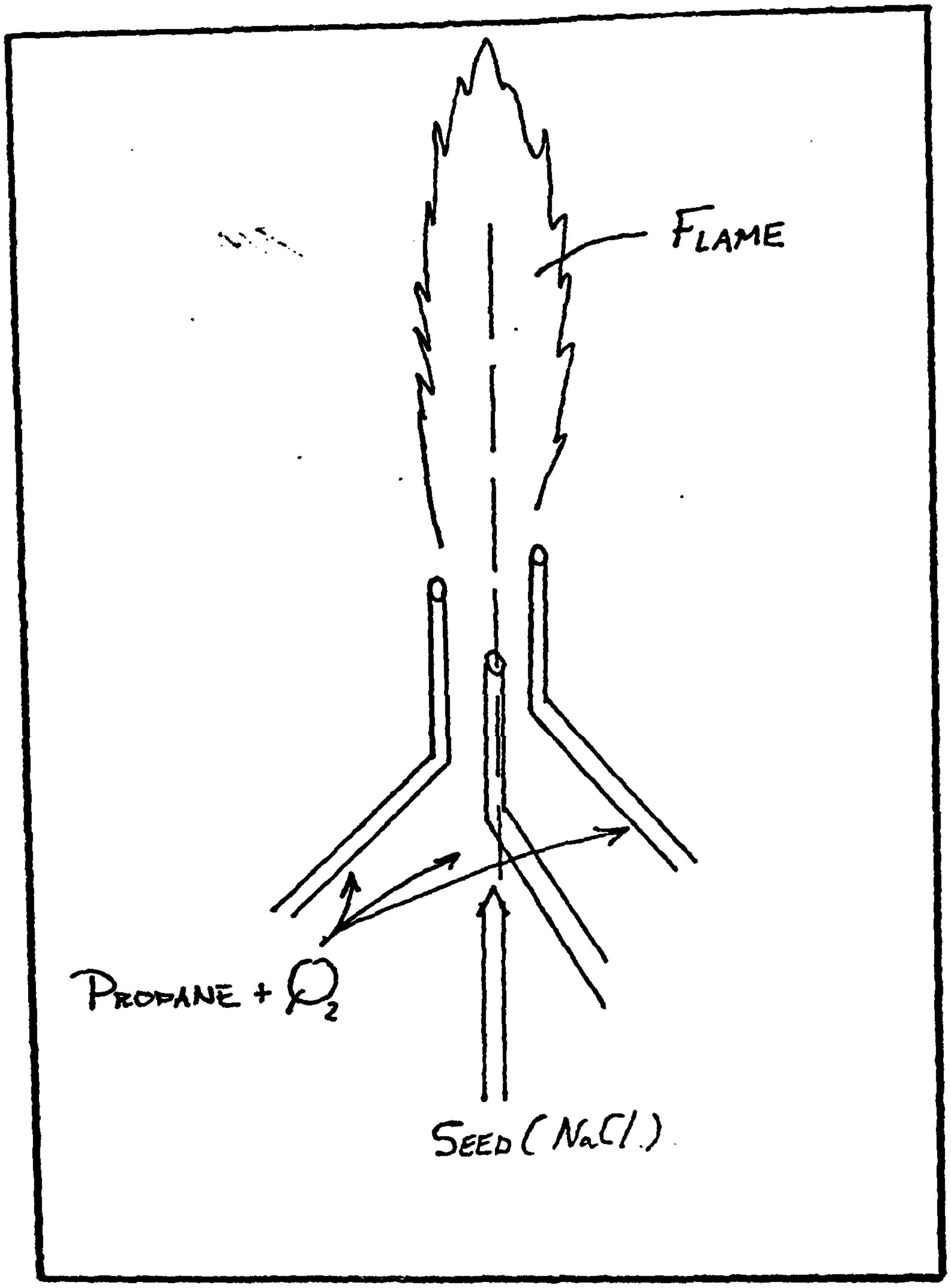
$$\bar{A}_{LEAD} = \frac{\mu_0 S_0}{4\pi}\left\{\sin(\phi-\phi')\hat{e}_r + \cos(\phi-\phi')\hat{e}_\phi\right\}(r^2+r_L^2-2rr_L\sin\phi)$$

$$\cdot\left[\frac{1}{(r^2+r_L^2-2rr_L\sin\phi+(z-D/2)^2)^{3/2}} - \frac{1}{(r^2+r_L^2-2rr_L\sin\phi+(z+D/2)^2)^{3/2}}\right]$$

WHERE $\phi' = \mathrm{TAN}^{-1}\left[\dfrac{r\sin\phi - r_L}{r\cos\phi}\right]$



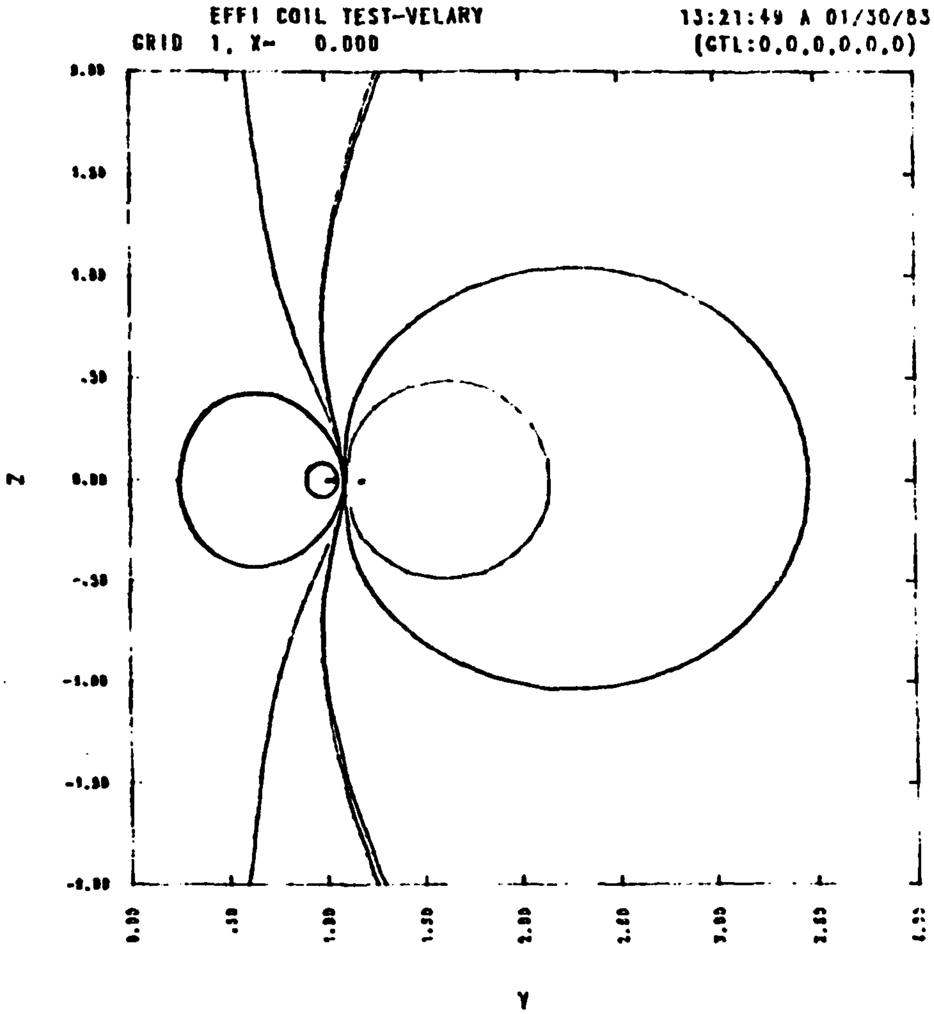
A_ϕ
20
10
-10
-20
-2
-1
0
1
2
Z
r = 1.0
z
1
y
x
R = 0.5


FLAME
PROPANE + O_2
SEED (NaCl)

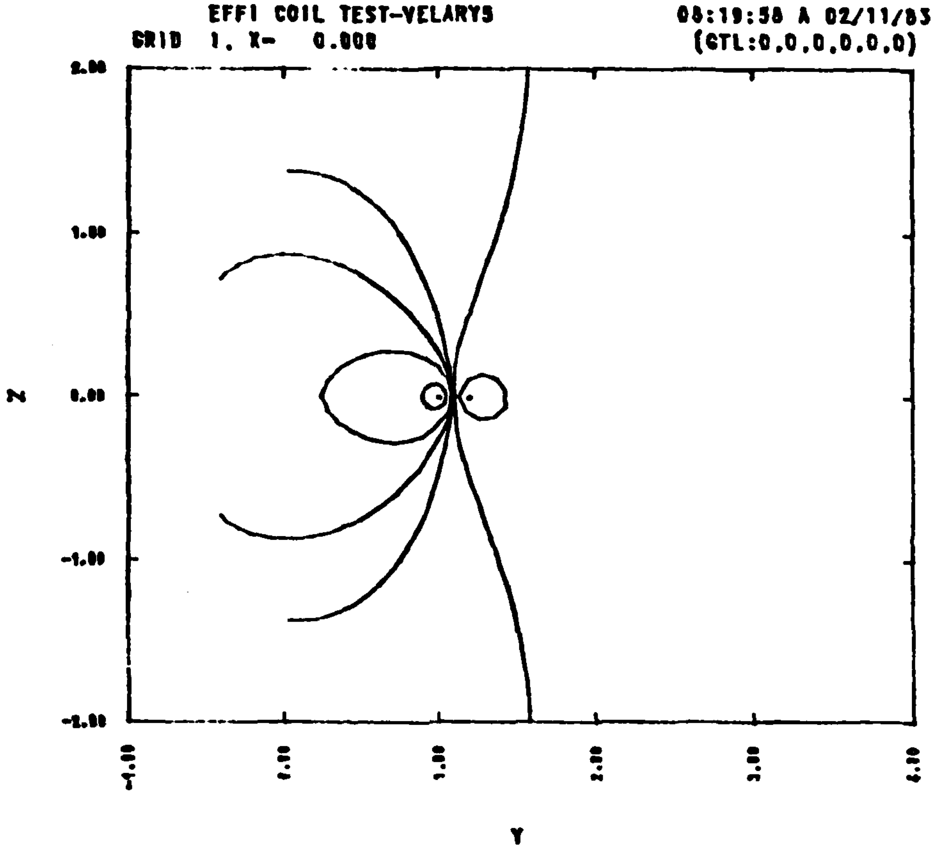
APPENDIX C

Outputs of Magnetic Field Line Following Computer Codes Applied to Velocimeter Coil Arrays

```
1      effi coil test-velarvc                                                        14:54:27 a 04/06/83     effi.05/19/8


       length     = cm                 p1 = 2.000e+01
       angle      = degree             p2 = 1.000e-05
       current    = a/cm**2            p3 = 1.000e-07
       b-field    = t                  p4 = 1.000e-05
       force      = n                  p5 = 1.000e-04
       inductance = h                  p6 = 5.000e+00

       zero tolerance =  1.000e-10



coil  1 (        ) *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***




circular loops

           x          y          z          a       alpha      beta        s1        s2        j
    1    2.0000     0.0000     0.0000     .5000     0.0000     0.0000     .0100     .0100   1.000e+04
    2    1.6200     1.1800     0.0000     .5000     0.0000     0.0000     .0100     .0100   1.000e+04
    3     .6180     1.9000     0.0000     .5000     0.0000     0.0000     .0100     .0100   1.000e+04
    4    -.6180     1.9000     0.0000     .5000     0.0000     0.0000     .0100     .0100   1.000e+04
    5   -1.6200     1.1800     0.0000     .5000     0.0000     0.0000     .0100     .0100   1.000e+04
    6   -2.0000     0.0000     0.0000     .5000     0.0000     0.0000     .0100     .0100   1.000e+04
1      effi coil test-velarvc                                                        14:54:27 a 04/06/83     effi.05/19/81


field line   1

      s          x          y          z        bx            by            bz           b         int(ds/b)
    0.0000     0.0000     1.0000     .5000  5.08220e-21 -9.94310e-06 -6.73766e-06  1.20e-05  0.
     .1000      .0000      .9233     .4361  0.           -8.57166e-06 -8.67323e-06  1.22e-05  8.27596e+03
     .2000      .0000      .8600     .3589  0.           -7.04736e-06 -1.03870e-05  1.26e-05  1.63650e+04
     .3000      .0000      .8112     .2717  0.           -5.36227e-06 -1.18108e-05  1.30e-05  2.42020e+04
     .4000      .0000      .7773     .1779  0.           -3.53067e-06 -1.28688e-05  1.33e-05  3.17981e+04
     .5000      .0000      .7582     .0797  0.           -1.59036e-06 -1.34931e-05  1.36e-05  3.92172e+04
     .6000      .0000      .7539    -.0201  0.            4.02210e-07 -1.36396e-05  1.36e-05  4.65527e+04
     .7000      .0000      .7641    -.1195  0.            2.38137e-06 -1.32974e-05  1.35e-05  5.39095e+04
     .8000      .0000      .7092    -.2162  0.            4.28382e-06 -1.24915e-05  1.32e-05  6.13898e+04
     .9000      .0000      .8290    -.3070  0.            6.05970e-06 -1.12773e-05  1.28e-05  6.90776e+04
    1.0000      .0000      .8837    -.3914  0.            7.68042e-06 -9.72765e-06  1.24e-05  7.70186e+04
    1.1000      .0000      .9527    -.4636  0.            9.14117e-06 -7.91738e-06  1.21e-05  8.51956e+04
    1.2000      .0000     1.0342    -.5212  0.            1.04569e-05 -5.90713e-06  1.20e-05  9.35087e+04
    1.3000      .0000     1.1257    -.5612  0.            1.16517e-05 -3.73204e-06  1.22e-05  1.01778e+05
    1.4000      .0000     1.2233    -.5819  0.            1.27423e-05 -1.39922e-06  1.28e-05  1.09782e+05
    1.5000     -.0000     1.3232    -.5833  0.            1.37201e-05  1.10151e-06  1.38e-05  1.17325e+05
    1.6000     -.0000     1.4216    -.5665  0.            1.45346e-05  3.77081e-06  1.50e-05  1.24289e+05
    1.7000     -.0000     1.5160    -.5338  0.            1.50769e-05  6.55278e-06  1.64e-05  1.30654e+05
    1.8000     -.0000     1.6046    -.4876  0.            1.51566e-05  9.25204e-06  1.78e-05  1.36496e+05
    1.9000     -.0000     1.6866    -.4305  0.            1.44555e-05  1.13676e-05  1.84e-05  1.42001e+05
    2.0000     -.0000     1.7621    -.3649  0.            1.24089e-05  1.17213e-05  1.71e-05  1.47566e+05

     dskadd=      0 (00000000b)
1      effi coil test-velarvc                                                        14:54:27 a 04/06/83     effi.05/19/81


field line   2

      s          x          y          z        bx            by            bz           b         int(ds/b)
    0.0000     0.0000     1.0000    1.0000  1.69407e-20 -5.47861e-06  1.67649e-06  5.73e-06  0.
     .1000      .0000      .9033    1.02[illegible]  0.           -5.04364e-06  1.09097e-06  5.16e-06  1.84170e+04
```


EFFI COIL TEST-VELARY
13:21:49 A 01/30/83
GRID 1, X= 0.000
(CTL:0,0,0,0,0,0)
Z
Y

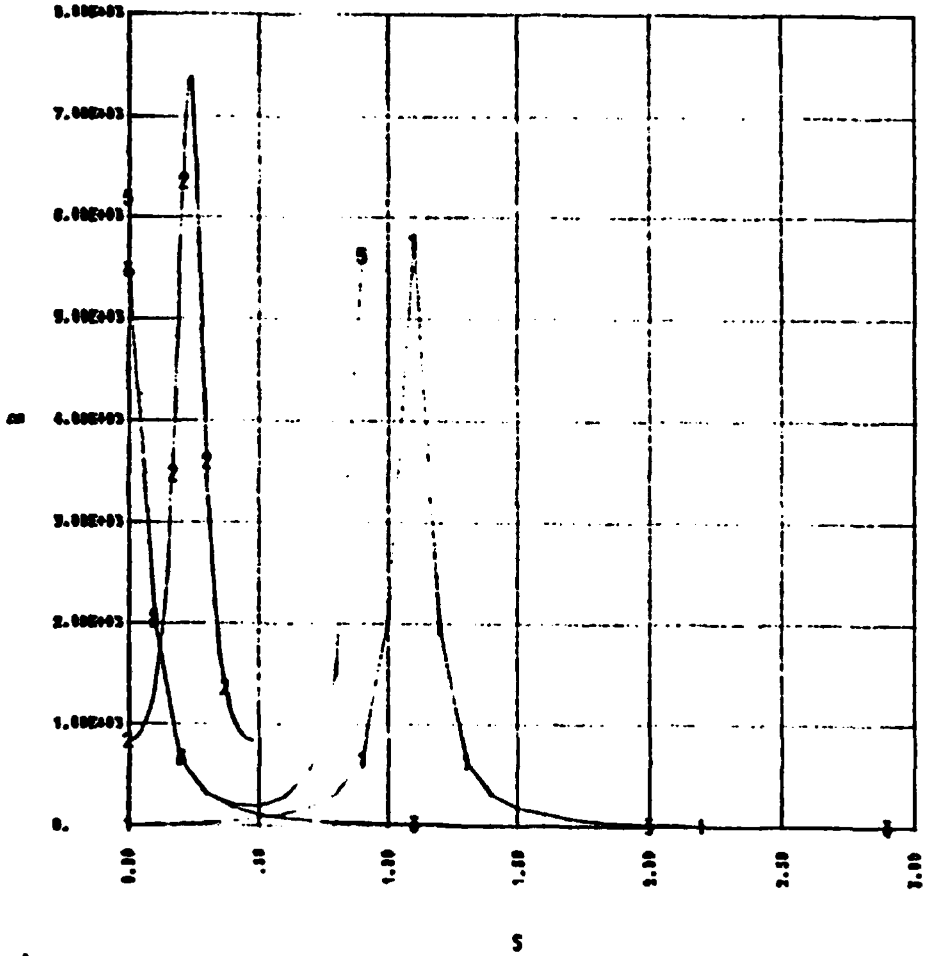
frame #4



EFFI COIL TEST-VELARYS
08:19:58 A 02/11/83
GRID 1, X= 0.000
(GTL:0,0,0,0,0,0)
2.00
1.00
0.00
-1.00
-2.00
Z
-1.00
0.00
1.00
2.00
3.00
4.00
Y

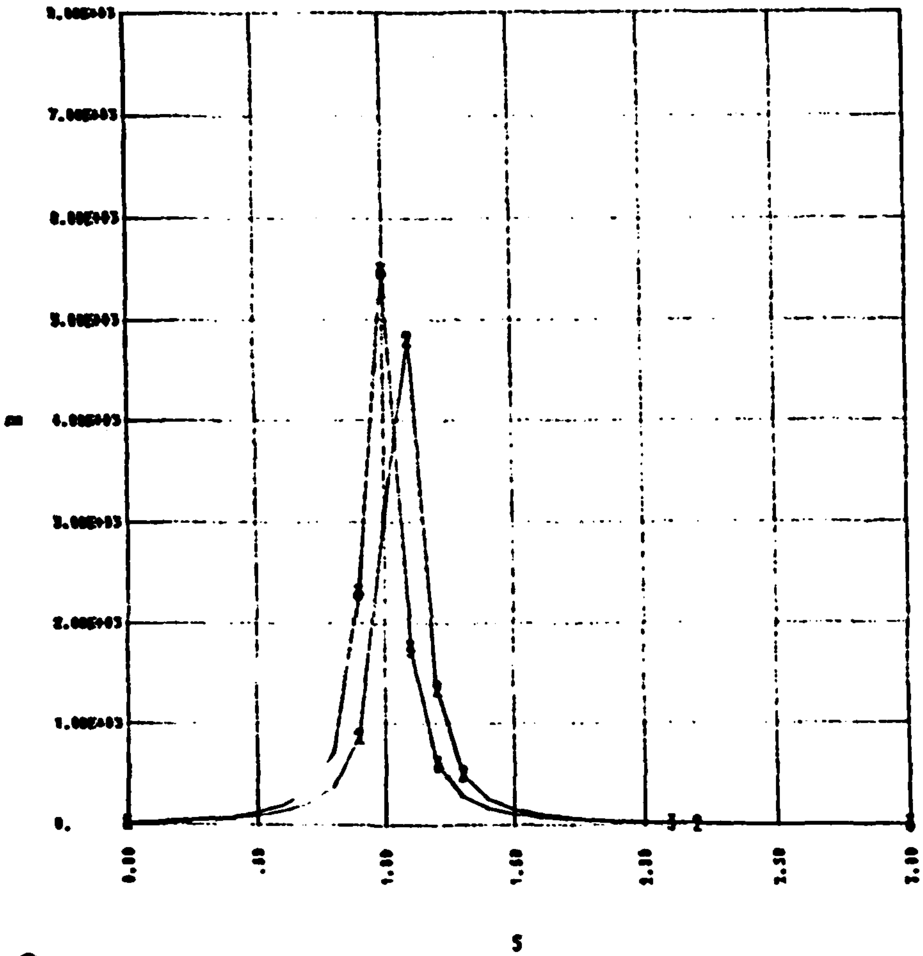
frame # 3.

EFFI COIL TEST-VELARYS 08:19:58 A 02/11/83
FIELD MAGNITUDE ALONG FLUX LINES 1 THROUGH 5



frame # 1.

EFFI COIL TEST-VELARY5 08:19:58 A 02/11/83
FIELD MAGNITUDE ALONG FLUX LINES 6 THROUGH 9



frame # 2.

APPENDIX D

Source Code (FORTRAN) for Computer Model of Velocimeter Response to Flow Systems

```
c       this consolidated code generates a computer model
c       of a lead field [illegible] probe of a conducting jet
c
c       **********  [illegible]  ********
c
c       set up dipole array by specifying parameter
c
        parameter([illegible])
        parameter([illegible])
        real dri([illegible])
        data dri/-1 [illegible] 0,-1 0,1 0/
        parameter(arrayl=100 0)
c
c       ************************************************
c
c       set up lead field array by specifying parameters
c
        parameter(ral1=1 0,ral2 [illegible] 1 0)
        parameter(zlead1=+1.5,zlead2=-1 5)
        parameter(rlead1=2 0,rlead2=2 0)
        parameter(philead1=[illegible] 0 philead2=90 0)
c
c       ************************************************
c
c       set up the observation array dimensions
c
        parameter(ni=11 nj=[illegible],nk=[illegible])
        real robs(ni),phiobs(nj),zobs(nk)
c
c       ************************************************
c
c       set up the velocity distribution vz(r,phi)
        parameter(mmax=4,nmax=1)
        real cosmmn(mmax,nmax),sinmmn(mmax,nmax)
        data cosmmn/1 0.0 0.0 0.0 0/
        data sinmmn/0 0.0 0.0 0.0.0/
        real vz(ni,nj)
        real amnn(5,4)
c
c       ************************************************
c
        real br([illegible]),bpo(ni,nj,nk),bzo(ni,nj,nk)
        real aro([illegible]),apo(ni,nj,nk)
        real arolead([illegible]),apolead(ni,nj,nk)
c
c       ************************************************
c
c       set up integrand arrays
c
        dimension rintg1(ni,nj,nk)
        dimension rintg2(nj,nk)
        dimension rintg11(nk)
        data rintg11/[illegible]0.0/
        dimension rintg[illegible]([illegible],nk)
        dimension rintg[illegible](nj,nk)
        dimension rintg1[illegible](nk)
        data rintg1[illegible]/[illegible]0/
c
c       ************************************************
c
        open(unit [illegible] file=[illegible]fusr1.dat',status='new')
```

```
c
c         ************************************************************
c
c         start the run time counter
c
          t1=seconds(0.0)
c
c         ************************************************************
c
c         note   ammn are the nn th root of the mm th bessel function
c         note   cmmnn, smmnn are the mm,nn-th cosine and sine coefficients
c         respectively of the bessel transform of the velocity
c
          data ammn/2.40483,3.83171,5.13562,6.38016,7.58834
     1 ,5.52007,7.01559,8.41724,9.76102,11.06471,8.65372,10.17347,
     4 11.61984,13.01520,14.37254,11.79153,13.32369,14.79595,
     5 16.22347,17.61597/
c
c         ************************************************************
c
          pi=3.1415927
          width=arraywid/(narray-1)
c
          write(1,200)rp,i0,narray,(wiv(i),i=1,narray),arraywid
200       format(5x,'a drive array is set up with the following
     1 specifications',///,10x,'rp=',f4.1,/,10x,'i0=',f5.3,
     2 /,10x,'number of array coils=',i2,/,10x,'weights=
     3 ',6(f6.3,3x),/,10x,'array width=',f5.1,////)
          write(1,300)zlead1,zlead2,rlead1,rlead2,philerd1,philerd2
     1 ,rai1,rai2
300       format(5x,'a lead field (probe) array is set up with the
     2 following specifications',///,10x,'zleadi=',f6.3,2x,f6.3
     3 ,/,10x,'rleadi=',f6.3,2x,f6.3,/,10x,'phileadi=',f5.1,
     4 2x,f5.1,/,10x,'aleadi=',e10.3,2x,e10.3)
          write(1,99)
99        format('1',37x,'these are the values for the vector fields in the
     2 flame jet region')
c
c         ************************************************************
c
c         construct the observation variables for the fields
c
          do 1 k=1,nk
          zobs(k)=0.5*(k-1)-2.0
          do 1 i=1,ni
          robs(i)=1.0*(i-1)/(ni-1)
c
c         set up labels for vector field value columns
          write(1,100)
100       format(//,3x,'     r      ',3x,'   phi    ',3x,'     z
     1       ',3x,'    br0    ',4x,' bphi0  ',4x,'    bz0
     2        ',1x,'    ar0    ',4x,' aphi0  ',4x,' arolead ',4x,' apolead ',/)
c
          do 2 j=1,nj
          phideg=360.0*(j-1)/(nj-1)
          phiobs(j)=(pi/180.0)*phideg
c
c         ************************************************************
c
c         construct the drive fields
c
```

```
          br0sum=0.0
          bp0sum=0.0
          bz0sum=0.0
          ar0sum=0.0
          ap0sum=0.0
          do 3 jjj=1,nalray
          phipdeg=width*(jjj-1)
          phip=(pi/180.0)*phipdeg
          rm01=driv(jjj)
          dphi=phiobs(j)-phip
          cs=cos(dphi)
          sn=sin(dphi)
          sqmag=robs(i)**2+r0**2-2.0*robs(i)*r0*cos(dphi)+(zobs(k)-z0)**2
          grn1=sqmag**1.5
          grn2=sqmag**2.5
          br0=rm01*3.0*(zobs(k)-zp)*(robs(i)-r0*cs)/grn2
          bp0=rm01*3.0*(zobs(k)-zp)*r0*sn/grn2
          bz0=rm01*(2.0*(zobs(k)-zp)**2-robs(i)**2-r0**2+2.0*robs(i)*r0*cs
         1 )/grn2
          ar0=-rm01*r0*sn/grn1
          ap0=rm01*(robs(i)-r0*cs)/grn1
          br0sum=br0sum+br0
          bp0sum=bp0sum+bp0
          bz0sum=bz0sum+bz0
          ar0sum=ar0sum+ar0
          ap0sum=ap0sum+ap0
    3     continue
          bro(i,j,k)=br0sum
          bpo(i,j,k)=bp0sum
          bzo(i,j,k)=bz0sum
          aro(i,j,k)=ar0sum
          apo(i,j,k)=ap0sum
    c
    c     ****************************************************
    c
    c     construct the lead field
    c
          philead1=phileda1*(pi/180.0)
          philead2=phileda2*(pi/180.0)
          dphil1=phiobs(j)-philead1
          dphil2=phiobs(j)-philead2
          dzlead1=zobs(k)-zlead1
          dzlead2=zobs(k)-zlead2
          cs1=cos(dphil1)
          cs2=cos(dphil2)
          sn1=sin(dphil1)
          sn2=sin(dphil2)
          sqmag1=robs(i)**2+rlead1**2-2.0*robs(i)*rlead1*cs1+dzlead1**2
          sqmag2=robs(i)**2+rlead2**2-2.0*robs(i)*rlead2*cs2+dzlead2**2
          grnl1=sqmag1**1.5
          grnl2=sqmag2**1.5
          arolead(i,j,k)=-rml1*rlead1*sn1/grnl1-rml2
         1 *rlead2*sn2/grnl2
          apolead(i,j,k)=rml1*(robs(i)-rlead1*cs1)/grnl1+
         2 rml2*(robs(i)-rlead2*cs2)/grnl2
          write(1,101)robs(i),phideg,zobs(k),bro(i,j,k),bpo(i,j,k),bzo(i,j,k)
         1 ,aro(i,j,k),apo(i,j,k),arolead(i,j,k),apolead(i,j,k)
  101     format(3x,f7.3,3x,f9.3,3x,f7.3,5x,e10.3,3x,e10.3,3x,e10.3,3x
         1     ,e10.3,3x,e10.3,3x,e10.3,3x,e10.3)
    2     continue
          write(1,102)
```

```
102     format(/)
1       continue
c
c       ************************************************************
c
c       construct velocity field as a bessel expansion
c
        write(1,87)
87      format('1','the velocity vector field is expressed thru its fourier-
       1 bessel expansion components as follows:',/)
        do 777 mco=1,mmax
        do 777 nco=1,nmax
        write(1,86)mco-1,nco,cosmmnn(mco,nco),sinmmnn(mco,nco)
86      format(6x,'for m=',i2,2x,'n=',i2,5x,'amn=',f9.3,5x,'bmn='
       2 ,f5.3)
777     continue
        write(1,89)(robs(i),i=1,11)
89      format(//,6x,'phi',5x,11(2x,'r=',f3.1,4x),/)
        do 53 nnj=1,nj
        phid=360.0*(nnj-1)/(nj-1)
        phi=phiobs(nnj)
        do 52 nni=1,ni
        r=robs(nni)
        visum=0.0
        do 333 mmm=1,mmax
        mm=mmm-1
        do 333 nn=1,nmax
        visum=visum+cosmmnn(mmm,nn)*bessel(mmm,r*zmmnn(mmm,nn))*cos
       1 (mm*phi)+sinmmnn(mmm,nn)*bessel(mmm,r*zmmnn(mmm,nn))*sin
       2 (mm*phi)
333     continue
        vz(nni,nnj)=visum
52      continue
        write(1,500)phid,(vz(i,nnj),i=1,ni)
500     format(3x,f5.1,1x,'deg',2x,11(e9.2,2x))
53      continue
c
c       ************************************************************
c
c       construct 3-dimensional integrands
c
        do 222 ith=1,ni
        do 222 jth=1,nj
        do 222 kth=1,nk
        rr=robs(ith)
        rintg31(ith,jth,kth)=rr*vz(ith,jth)*(bro(ith,jth,kth)*
       1 apolead(ith,jth,kth)-bpo(ith,jth,kth)*arolead(ith,jth,kth))
        rintg32(ith,jth,kth)=rr*(aro(ith,jth,kth)*arolead(ith,jth,kth)
       2 +apo(ith,jth,kth)*apolead(ith,jth,kth))
222     continue
c
c       ************************************************************
c
c       implement three dimensional integrations
c
        dr=1.0/(ni-1)
        dp=2.0*pi/(nj-1)
        dz=4.0/(nk-1)
        do 22 ii=1,nk
        do 22 jj=1,nj
        rintg21(jj,ii)=0.0
```

```
        rintg22(jj,ii)=0.0
        do 22 kk1=1,nt-2,2
        kk2=kk1+1
        kk3=kk1+2
        rintg21(jj,ii)=rintg21(jj,ii)+rintg31(kk1,jj,ii)+4.0*
        1 rintg31(kk2,jj,ii)+rintg31(kk3,jj,ii)
        rintg22(jj,ii)=rintg22(jj,ii)+rintg32(kk1,jj,ii)+4.0*
        1 rintg32(kk2,jj,ii)+rintg32(kk3,jj,ii)
22      continue
        do 33 ii=1,nb
        rintg11(ii)=0.0
        rintg12(ii)=0.0
        do 33 jj1=1,nj-2,2
        jj2=jj1+1
        jj3=jj1+2
        rintg11(ii)=rintg11(ii)+rintg21(jj1,ii)+4.0*rintg21(jj2,ii)
        1 +rintg21(jj3,ii)
        rintg12(ii)=rintg12(ii)+rintg22(jj1,ii)+4.0*rintg22(jj2,ii)
        1 +rintg22(jj3,ii)
33      continue
c       sum1 is the velocity contribution
c       sum2 is the eddy contribution
        sum1=0.0
        sum2=0.0
        do 44 ii1=1,nk-2,2
        ii2=ii1+1
        ii3=ii1+2
        sum1=sum1+rintg11(ii1)+4.0*rintg11(ii2)+rintg11(ii3)
        sum2=sum2+rintg12(ii1)+4.0*rintg12(ii2)+rintg12(ii3)
44      continue
        sum1=sum1*dr*dp*dz/27.0
        sum2=sum2*dr*dp*dz/27.0
        write(1,400)sum1,sum2
400     format(//,5x,'the velocity contribution to the output=',e9.3,3x,'the
        2 eddy contribution=',e9.3,3x,'for this expansion component')
c
c       ****************************************************
c
c       determine and print the elapsed time for the calculation
c
        delta=secnds(t1)
        write(1,401)delta
401     format(///,10x,'the elapsed time for this run (in seconds) =',f9.3)
        stop
        end
c
c            FUNCTION SUBPROGRAM BESSEL
c
        real function bessel(m,arg)
        real j(10),sj0,sj1,lj0,lj1
             if(abs(arg).le.3.0)then
        j(1)=sj0(arg/3.0)
        j(2)=sj1(arg/3.0)
             else
        arginv=3.0/arg
        j(1)=lj0(arginv)
        j(2)=lj1(arginv)
             endif
             if(m.le.2)then
        bessel=j(m)
             elseif(arg.eq.0.0)then
```

```
      bessel=0.0
         else
      do 2 k=3,m
      j(k)=2*(k-2)*j(k-1)/arg - j(k-2)
2     continue
      bessel=j(m)
         endif
      return
      end
c
         FUNCTION SUBPROGRAM SJO(X)
c
      real function sj0(x)
      real*8 xd,a(12),sum
      xd=x
      do 3 i=1,12
3     a(i)=0.0
c
c     coefficients for sj0
c
      a(2)=2.2499997
      a(4)=1.2656208
      a(6)=.3163866
      a(8)=.0444479
      a(10)=.0039444
      a(12)=.0002100
c

      sum=1.0
      do 1 k=1,6
      sum =sum+(-1.0)**k*a(2*k)*(xd**(2*k))
1     continue
      sj0=sum
      return
      end
c
         FUNCTION SUBPROGRAM LJO(X)
c
      real function lj0(x)
      real*8 xd,b(6),c(6),f0,theta0,pi,rad
      xd=x
      pi=3.14159265
c
c     coefficients for lj0 (f0)
c
      b(1)=.00000077
      b(2)=.00552740
      b(3)=.00009512
      b(4)=.00137237
      b(5)=[illegible]
      b(6)=.00014476
c
c     coefficients for lj0 (theta0)
c
      c(1)=.04166397
      c(2)=.00003954
      c(3)=.00262573
      c(4)=.00054125
      c(5)=.00029333
      c(6)=.00013558
c
```

```
      f0= 79788456 [illegible] xd [illegible] b( [illegible] (xd**2) [illegible] b( [illegible] (xd**3))
     1 + b(4)*(xd**4) [illegible] b( [illegible] (xd**5) + b(6)*(xd**6)
      theta0=3 0/xd [illegible] c(1)*xd [illegible] c(2)*(xd**2) + c(3)*(xd**3)
     1 [illegible] c(4)*(xd**4) [illegible] c(5)*(xd**5) + c(6)*(xd**6)
      lj0=dsqrt( [illegible] cos(theta0)
      return
      end
c
c          FUNCTION SUBPROGRAM SJ1(X)
c
      real function [illegible]
      real*8 xd,d( [illegible] sum
      xd=x
      do 2 i=1,12
2     d(i)=0 0
c
c     coefficients for sj1
c
      d(2)= 56249985
      d(4)= 21093573
      d(6)=.03954289
      d(8)= 00443319
      d(10)=.00031761
      d(12)=.00001109
c
      sum=.50
      do 1 k=1,6
      sum=sum + d(2*k)*(-1 0)**k * (xd**(2*k))
1     continue
      sj1=3 0*xd*sum
      return
      end
c
c          FUNCTION SUBPROGRAM LJ1(X)
c
      real function lj1(x)
      real*8 xd,e(5),f(6),f1,theta1,pi,rad
      xd=x
c
c     coefficients for lj1 (f1)
c
      e(1)= 00000156
      e(2)= 01659667
      e(3)= 00017105
      e(4)=.00249511
      e(5)=.00113653
      e(6)=.00020033
c
c     coefficients for lj1 (theta1)
c
      f(1)=.12499612
      f(2)= 00005650
      f(3)=.00637879
      f(4)=.00074348
      f(5)= 00079824
      f(6)= 00029166
c
      f1=.79788456 + e(1)*xd + e(2)*(xd**2) +e(3)*(xd**3)
     1 - e(4)*(xd**4) + e(5)*(xd**5) - e(6)*(xd**6)
      theta1=3 0/xd - 2 35619449 + f(1)*xd + f(2)*(xd**2)
     1 - f(3)*(xd**3) + f(4)*(xd**4) + f(5)*(xd**5) - f(6)*(xd**6)
```

```
ljl=dsqrt(sd/3.0)*fl*cos(theta1)
return
end
```

APPENDIX E

Output of Computer Model for Velocimeter and Flow System

[illegible] values for the vector fields in the flame jet region

r	phi	[illegible]	[illegible]	bphi0	bz0	[illegible]	aphi0	[illegible]	[illegible]
0.000	0.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.231E+00	-0.190E+00	[illegible]
0.000	15.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.197E+00	[illegible]	[illegible]
0.000	30.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.140E+00	[illegible]	[illegible]
0.000	45.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.909E-01	0.140E+00	[illegible]
0.000	60.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.292E-01	-0.909E-01	[illegible]
0.000	75.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.405E-01	-0.512E-01	0.191E+00
0.000	90.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.104E+00	0.000E+00	[illegible]
0.000	105.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.160E+00	0.512E-01	[illegible]
0.000	120.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.196E+00	0.909E-01	[illegible]
0.000	135.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.140E+00	[illegible]
0.000	150.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.171E+00	[illegible]
0.000	165.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.250E+00	0.191E+00	[illegible]
0.000	180.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.190E+00	[illegible]
0.000	195.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.191E+00	[illegible]
0.000	210.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.171E+00	0.989E-01
0.000	225.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.707E-01	0.140E+00	-0.140E+00
0.000	240.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.292E-01	0.989E-01	[illegible]
0.000	255.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.409E-01	0.512E-01	[illegible]
0.000	270.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.104E+00	-0.173E-07	[illegible]
0.000	285.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.512E-01	[illegible]
0.000	300.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.909E-01	[illegible]
0.000	315.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.212E+00	-0.140E+00	[illegible]
0.000	330.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.171E+00	[illegible]
0.000	345.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.191E+00	[illegible]
0.000	360.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.190E+00	[illegible]

r	phi	[illegible]	[illegible]	bphi0	bz0	[illegible]	aphi0	[illegible]	[illegible]
0.100	0.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.231E+00	[illegible]	[illegible]
0.100	15.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.190E+00	[illegible]	[illegible]
0.100	30.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.152E+00	[illegible]	[illegible]
0.100	45.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.955E-01	-0.156E+00	[illegible]
0.100	60.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.329E-01	[illegible]	[illegible]
0.100	75.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.100	90.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.100	105.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.150E+00	[illegible]	[illegible]
0.100	120.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.100	135.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.100	150.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.100	165.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.100	180.000	[illegible]	[illegible]	[illegible]	[illegible]	0.100E+00	0.231E+00	[illegible]	[illegible]
0.100	195.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.100	210.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.100	225.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.100	240.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.100	255.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.100	270.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.100	285.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.100	300.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.100	315.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.100	330.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.100	345.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.100	360.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible] expansion component, [illegible]

[illegible]

phi	r=0.0	r=0.1	r=0.2	r=0.3	r=0.4	r=0.5	[illegible]	[illegible]	r=0.8	r=0.9	r=1.0
0.0 deg	[illegible]	[illegible]	0.94E+00	[illegible]	0.78E+00	0.67E+00	0.54[illegible]	[illegible]	0.27E+00	0.13E+00	0.29E-05
15.0 deg	0.10E+01	0.97E+00	0.96E+00	[illegible]	0.89E+00	0.83E+00	0.74[illegible]	[illegible]	0.43E+00	0.22E+00	0.32E-05
30.0 deg	[illegible]	0.99E+00	0.97E+00	[illegible]	0.93E+00	0.90E+00	[illegible]	[illegible]	0.50E+00	0.26E+00	0.33E-05
45.0 deg	0.10E+01	0.99E+00	0.96E+00	[illegible]	0.89E+00	0.83E+00	0.74[illegible]	[illegible]	0.43E+00	0.22E+00	0.32E-05
60.0 deg	0.10E+01	0.97E+00	0.94E+00	0.87E+00	0.78E+00	0.67E+00	0.54[illegible]	[illegible]	0.27E+00	0.13E+00	0.29E-05
75.0 deg	0.10E+01	0.98E+00	0.92E+00	[illegible]	0.67E+00	0.51E+00	[illegible]	[illegible]	0.10E+00	0.40E-01	0.26E-05
90.0 deg	0.10E+01	0.98E+00	0.92E+00	0.80E+00	0.63E+00	0.44E+00	[illegible]	[illegible]	0.36E-01	0.27E-02	0.24E-05
105.0 deg	0.10E+01	[illegible]	0.92E+00	[illegible]	[illegible]	0.51E+00	[illegible]	[illegible]	0.10E+00	0.40E-01	0.26E-05
120.0 deg	0.10E+01	0.97E+00	0.94E+00	[illegible]	0.78E+00	0.67E+00	0.54[illegible]	[illegible]	0.27E+00	0.13E+00	0.29E-05
135.0 deg	0.10E+01	0.99E+00	0.96E+00	[illegible]	0.89E+00	0.83E+00	0.74[illegible]	[illegible]	0.43E+00	0.22E+00	0.32E-05
150.0 deg	0.10E+01	0.99E+00	0.97E+00	[illegible]	0.93E+00	0.90E+00	[illegible]	[illegible]	0.50E+00	0.26E+00	0.33E-05
165.0 deg	0.10E+01	[illegible]	[illegible]	[illegible]	0.89E+00	0.83E+00	[illegible]	[illegible]	0.43E+00	0.22E+00	0.32E-05
180.0 deg	[illegible]	[illegible]	0.94E+00	[illegible]	0.78E+00	0.67E+00	0.54[illegible]	[illegible]	0.27E+00	0.13E+00	0.29E-05
195.0 deg	[illegible]	[illegible]	[illegible]	[illegible]	0.67E+00	0.51E+00	0.34[illegible]	[illegible]	0.10E+00	0.40E-01	0.26E-05
210.0 deg	[illegible]	[illegible]	0.92E+00	[illegible]	0.63E+00	0.44E+00	0.26[illegible]	[illegible]	0.36E-01	0.27E-02	0.24E-05
225.0 deg	[illegible]	[illegible]	0.92E+00	[illegible]	0.67E+00	0.51E+00	0.34[illegible]	[illegible]	0.10E+00	0.40E-01	0.26E-05
240.0 deg	[illegible]	[illegible]	0.94E+00	[illegible]	0.78E+00	0.67E+00	0.54[illegible]	[illegible]	0.27E+00	0.13E+00	0.29E-05
255.0 deg	[illegible]	[illegible]	0.96E+00	[illegible]	0.89E+00	0.83E+00	0.74[illegible]	[illegible]	0.43E+00	0.22E+00	0.32E-05
270.0 deg	[illegible]	[illegible]	0.97E+00	[illegible]	0.93E+00	0.90E+00	[illegible]	[illegible]	0.50E+00	0.26E+00	0.33E-05
285.0 deg	[illegible]	0.99E+00	0.96E+00	[illegible]	0.89E+00	0.83E+00	0.74E+00	[illegible]	0.43E+00	0.22E+00	0.32E-05
300.0 deg	[illegible]	0.97E+00	0.94E+00	0.87E+00	0.78E+00	0.67E+00	0.54E+00	0.41E+00	0.27E+00	0.13E+00	0.29E-05
315.0 deg	[illegible]	0.98E+00	0.92E+00	[illegible]	0.67E+00	0.51E+00	0.34E+00	0.21E+00	0.10E+00	0.40E-01	0.26E-05
330.0 deg	[illegible]	[illegible]	0.92E+00	0.80E+00	0.63E+00	0.44E+00	0.26E+00	[illegible]	0.36E-01	0.27E-02	0.24E-05
345.0 deg	[illegible]	0.98E+00	0.92E+00	[illegible]	0.67E+00	0.51E+00	0.34E+00	0.21E+00	0.10E+00	0.40E-01	0.26E-05
360.0 deg	[illegible]	0.97E+00	0.94E+00	0.87E+00	0.78E+00	0.67E+00	0.54E+00	0.41E+00	0.27E+00	0.13E+00	0.29E-05

the velocity contribution to the output= 0.67E-01 the eddy contribution=-0.74E-08 for this expansion component

the elapsed time for this run (in seconds) = 51.242

APPENDIX F

Abstract for AFOSR/AFRPL Chemical Rocket

Research Meeting, February 28 - March 3, 1983

EXPERIMENTAL DEMONSTRATION OF MAGNETICALLY

COUPLED VELOCIMETERS

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A program of experimental verification is underway which will demonstrate the feasibility of a totally non-intrusive flow-field diagnostic for weakly turbulent, high temperature chemically reacting flows. This effort follows a phase of theoretical analysis and computer simulation to demonstrate the approach conceptually. This effort will result in viable designs for AC magnetic field-coupled velocimeters capable of measuring the mean and the turbulent velocity structure of flow-fields typical of rocket combustion chambers and exhaust nozzles.

Approach

An array of AC magnetic field generating coils exposes a combustion flow-field to a field structure which, as an applied field, can be modified at will. Induced perturbations in that field due to eddy effects (due to flow conductivity) and motional effects (due to across field motion of the flow) are picked up by an array of probe coils. Both arrays are external to the flow. The voltage measured by the probe array has been previously shown through theoretical analysis to be relateable to weighted moments (i.e., integral moments) over the spatial structure of the velocity flow-field. The applied field structure is controlled in such a way as to yield a finite and unique number of moments from which the velocity structure can be inferred. Previous efforts by other researchers to develop inductive flowmeters based on magnetic coupling have either not sought to unfold the velocity structure from their data or have had no way to uniquely and explicitly design the moments being measured. The use, however, in this effort of lead field theoretic analysis as a design basis has made that possible.

The experimental phase of the effort has three major components:

1. Design and testing of a data acquisition/processor system
2. Construction of propane combustor test station
3. Assembly of the probe and drive arrays

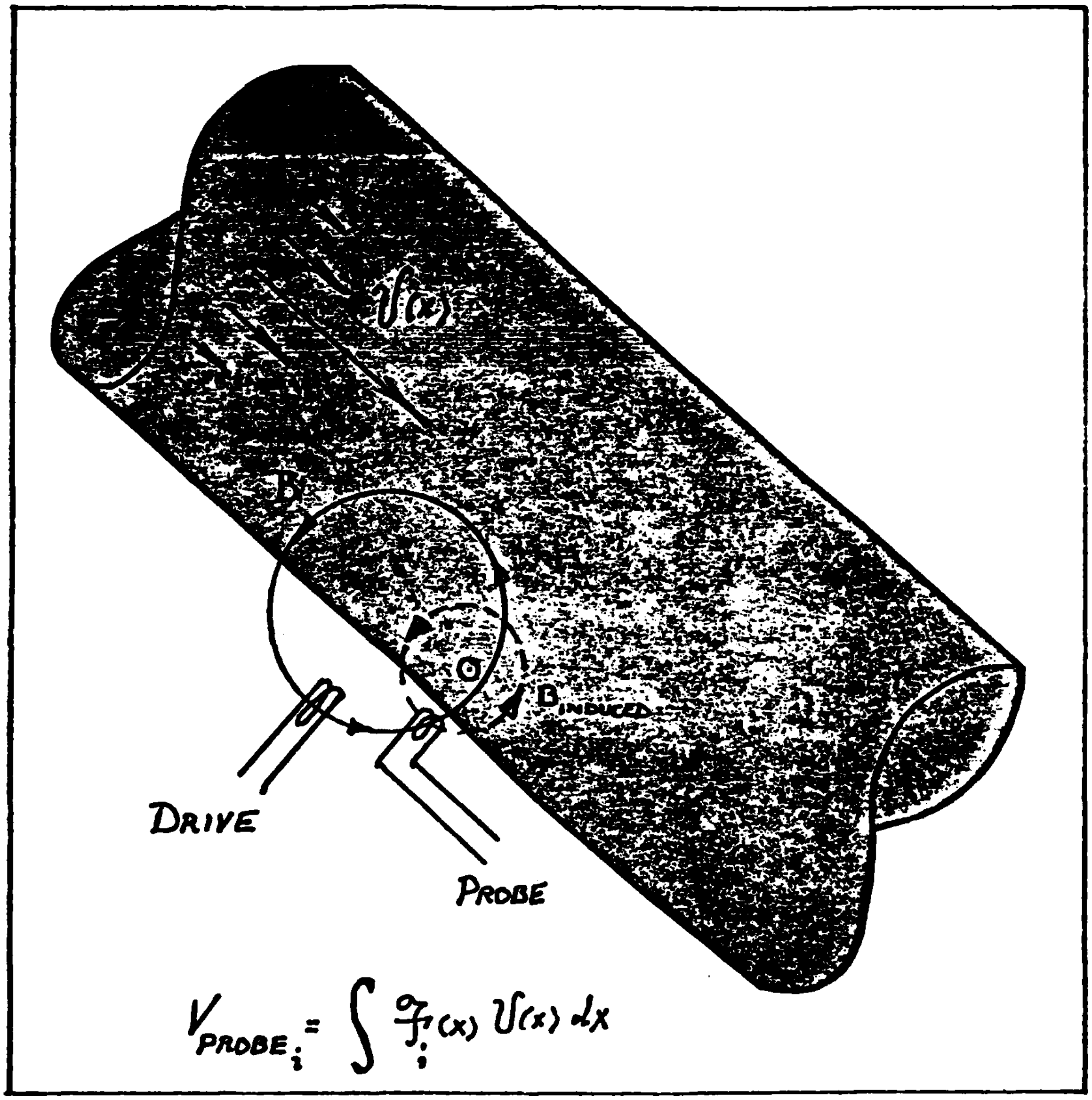

FIG 1

Span of Research Program: Dec 1980-Dec 1983

Accomplishments of Year Two (Dec 1981-Dec 1982):

a. Design and construction of propane combustion test stand
b. Design and construction of data acquisition/processor (DA/DP) system

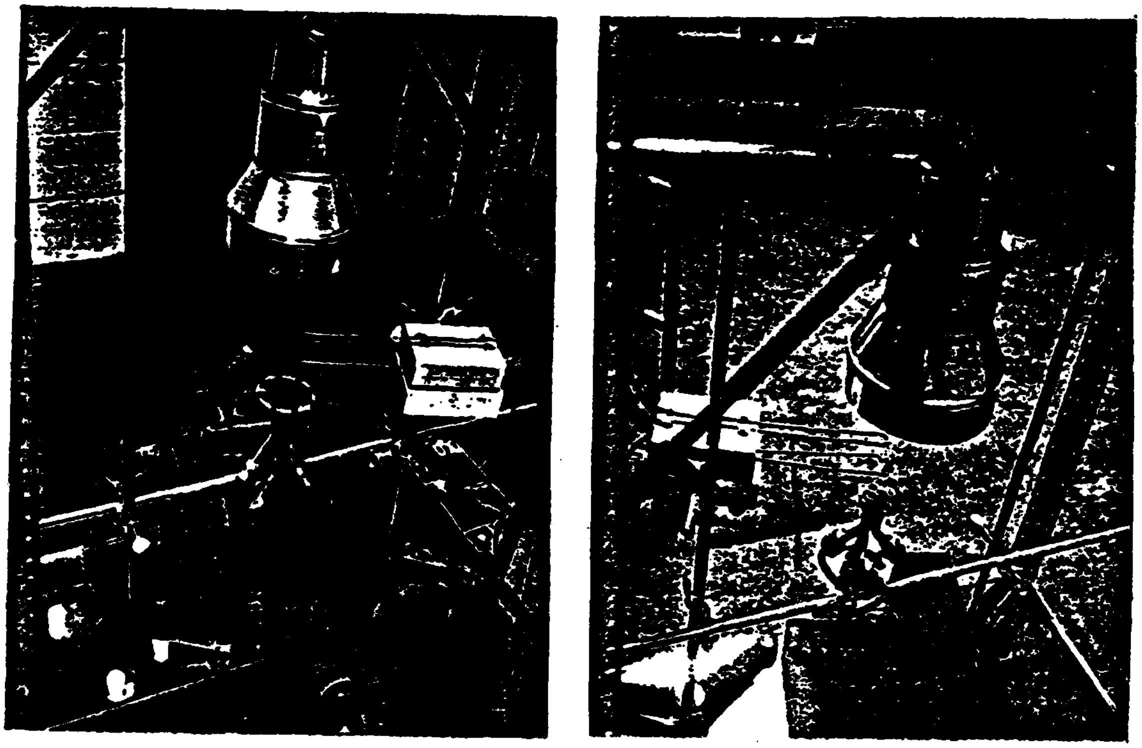

FIG 2 a.

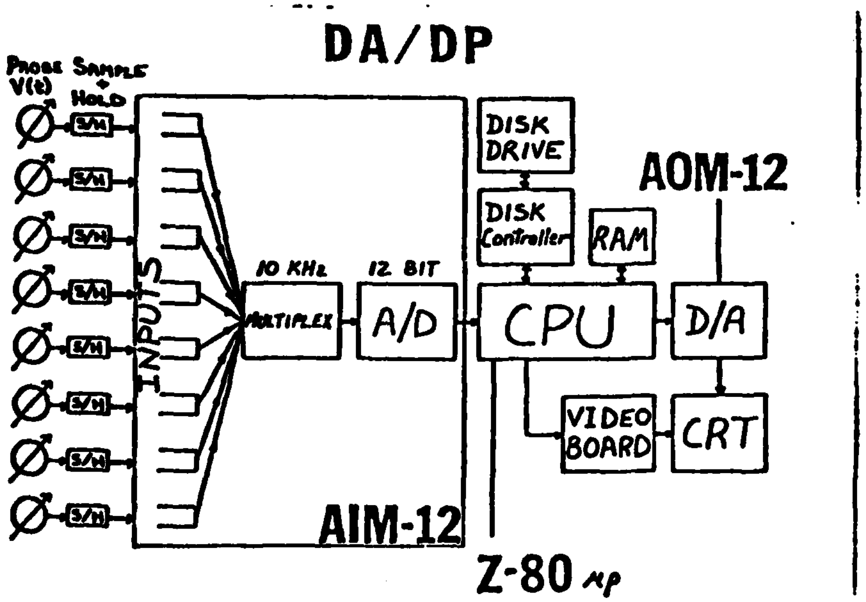

FIG 2 b.